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PREDICTIVE MODELING FOR THE PROPOSED TENNESSEE COLONY LAKE BASE--ETC(U)
JUL 78 J A NUSSER, P J YOUNG DACW63-77-C-0003

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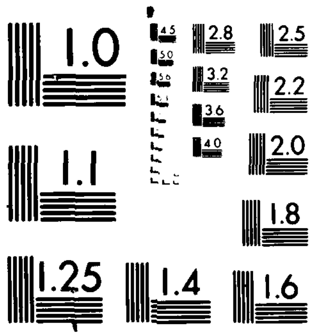

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REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER 6	2. GOVT ACCESSION NO. AD-A097 341	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) Predictive modeling for the proposed Tennessee Colony Lake based upon Eutrophication analysis of Lake Livingston, Texas, (phase II)		5. TYPE OF REPORT & PERIOD COVERED 9 final rept.
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) 10 Joseph A. Nusser, P. Jonathan Young		8. CONTRACT OR GRANT NUMBER(s) 15 DACW63-77-C-0003
9. PERFORMING ORGANIZATION NAME AND ADDRESS Hydroscience, Inc. 611 Ryan Plaza Drive, Suite 230 Arlington, Texas 76011		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS Fort Worth District, Corps of Engineers Engineering Division, Plng Br., SWFED-P POB 17300, Ft Worth, Texas 76102		12. REPORT DATE 11 July 1978
		13. NUMBER OF PAGES 95 pages
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office) NA 12 98		15. SECURITY CLASS. (of this report) Unclas
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

Phase II of a two-part study.

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Tennessee Colony Lake
Lake Livingston, Texas
lake eutrophication models
Predictive modeling

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The report discusses the investigations of water quality in the interim pool configuration of the proposed Tennessee Colony Lake. A eutrophication model, which had been developed in Phase I of this study, was applied to project chlorphyll 'a' trends in the interim lake. A BOD_5-DO sub-model was added and used to investigate dissolved oxygen trends. In addition, a previously developed water quality model for the Trinity River was used to estimate the projected dissolved oxygen profiles in the headwaters of the proposed lake

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20. and in the portion of the river immediately downstream of the dam. A summary and the conclusions of the study are also presented. In summary, phase II examined the predicted water quality and eutrophication conditions in the lake and evaluated the predicted dissolved oxygen conditions in the lake headwaters and in the Trinity River below the dam.

PREDICTIVE MODELING FOR THE PROPOSED TENNESSEE COLONY LAKE BASED UPON EUTROPHICATION ANALYSIS OF LAKE LIVINGSTON, TEXAS

(PHASE II)

Prepared under contract DACW63-77-C-0003
for the Fort Worth District, U.S. Army Corps of Engineers
by

Arlington, Texas
Westwood, New Jersey

Hydroscience

July 14, 1978

Mr. Robert E. Lyman
Department of the Army
Fort Worth District, Corps of Engineers
P.O. Box 17300
Fort Worth, Texas 76102

Dear Mr. Lyman:

We are pleased to submit herewith our report, "Predictive Modeling for the Proposed Tennessee Colony Lake Based Upon Eutrophication Analysis of Lake Livingston, Texas (Phase II)," prepared under Contract DACW63-77-C-0003 with the U.S. Army Corps of Engineers, Fort Worth, Texas.

The report discusses the investigations of water quality in the interim pool configuration of the proposed Tennessee Colony Lake. A eutrophication model, which had been developed in Phase I of this effort, was applied to project chlorophyll 'a' trends in the interim lake. A BOD_5-DO sub-model was added and used to investigate dissolved oxygen trends. In addition, a previously developed water quality model for the Trinity River was used to estimate the projected dissolved oxygen profiles in the headwaters of the proposed lake and in the portion of the river immediately downstream of the dam. A summary and the conclusions of the work effort are also presented.

May we express our appreciation for your cooperation and helpful assistance, as well as that of your staff. The members of the Hydroscience, Inc., staff who contributed directly to this portion of the work effort include John Novak, Alan H. Plummer, Jr., Dominic M. Di Toro, John L. Mancini, Walter Chiang, Roger Segura, and Claudia Zahorcak.

Respectfully submitted,

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SUMMARY AND CONCLUSIONS

CHAPTER I
SUMMARY AND CONCLUSIONS

This project report discusses Phase II of the work effort under Contract DACW63-77-C-0003 with the Fort Worth District, U.S. Army Corps of Engineers. This work effort involved the development and application of predictive models to evaluate the impact of the proposed Tennessee Colony Lake on the Trinity River, Texas. Specifically, Phase II deals with the interim pool configuration of the lake (elevation 240 feet), whereas Phase I dealt with the final configuration (elevation 275 feet). The Phase II effort examined the predicted water quality and eutrophication conditions in the lake and evaluated the predicted dissolved oxygen conditions in the lake headwaters and in the Trinity River below the dam.

The following paragraphs summarize the major results of Phase II of this study:

<u>Model Configurations</u>

1. The geometry of the interim pool was estimated using available topographic maps and channel cross-sectional data. Two configurations were developed for analysis: a) a completely-mixed, single-segment configuration with a total volume of 109,900 acre-ft, a total surface area of 15,100 acres, and an average depth of 7.3 feet; and b) a six-segment model with three deep main channel segments and three shallow bay segments. The six segments consist of one channel and two shallow segments in the lower reservoir, one channel and one shallow segment in the middle reservoir and one upper channel, or headwater, segment.

2. The two annual flow regimes developed in the Phase I effort--a low May flow and a high May flow--were used as the bases for evaluating the interim pool. Estimates of daily loadings of BOD_5, nitrogen, phosphorus, and suspended solids from the Trinity River inflow were based upon rating curves of concentrations versus flow developed in Phase I.

Chlorophyll 'a' Simulations

3. The eutrophication model framework, which was calibrated and validated in Phase I for Lake Livingston, was applied to the proposed Tennessee Colony Lake for both the completely-mixed and six-segment configurations during low and high flow hydrologies. The models predicted daily concentrations of nutrients, solids, and chlorophyll 'a' in the completely-mixed segment and each of the six separate segments. Chlorophyll 'a' was previously determined to be an adequate indicator of algal numbers and of primary productivity. The sensitivity of the six-segment model's chlorophyll 'a' results to the rate of horizontal dispersion was also examined by making alternate model runs with the dispersion rate reduced to the lower bound value for lakes.

4. The six-segment model indicates that, under low May flow hydrology, chlorophyll 'a' concentrations in various sections of the reservoir are projected to range from 5 to 130 μg/l. Concentrations in the upper channel segments remain at relatively low levels until midsummer, at which time substantial growth to levels of approximately 100 μg/l is expected to occur. By contrast, in the shallow segments high levels of chlorophyll 'a', between 60 and 130 μg/l, are projected for much of the year.

5. Under high May flow hydrology, projected chlorophyll 'a' trends in the upper channel segments are similar to those under low flow. In the shallow segments, moderately high chlorophyll concentrations exist during the spring which then decline in early summer due to the flushing by the high flow in May. Mid-summer peaks of over 100 μg/l are then experienced in these shallow segments and are followed by sustained levels between 60 and 100 μg/l through the fall and early winter.

6. The patterns of chlorophyll 'a' concentration projected by the completely-mixed model are essentially the same as those projected in the lower reservoir segments by the six-segment model.

Lake Model Dissolved Oxygen Studies

7. A biochemical oxygen demand/dissolved oxygen model was developed and linked to the six-segment Tennessee Colony Lake eutrophication model. This model, unlike the eutrophication model, has not been calibrated through testing with the Lake Livingston eutrophication model or through comparison with measured values of DO. A BOD_5 rating curve was developed to determine flow related loadings from the Trinity River. Daily values of DO in each of the six segments were predicted under both flow regimes.

8. In order to evaluate the impact of the upstream loadings relative to the internally-created algal effects, the model was also run with algal activity suppressed and with only upstream sources of BOD_5 as inputs.

9. The BOD_5 rating curve was adjusted to reflect two improved levels of municipal wastewater treatment, with BOD_5 effluent concentrations of 10 mg/l and

5 mg/l, which could occur in the future. Daily lake dissolved oxygen levels were calculated using the two adjusted BOD_5 loading curves, with and without the effect of algal activity, for both flow regimes.

10. Dissolved oxygen levels in the lake may be sensitive to the degree of treatment of municipal wastewater generated in the Dallas/Fort Worth area. Under present loadings and low flow hydrology, dissolved oxygen concentrations in the shallow segments of the lake are projected to remain close to or slightly greater than saturation throughout the year. The upper channel segments, however, will be affected by the incoming BOD_5 loads. The lake model indicates that the June and July DO's are projected to dip below 3 mg/l in the uppermost channel segments. In these segments, recovery in the late summer and early fall is then followed by a less severe dissolved oxygen depression in November.

11. Under the high May flow hydrology and present BOD_5 loadings, DO values in June and July are projected to range from a low of 2 mg/l in the upper channel to a low of 6 mg/l in the shallow segments in the main body of the lake. A second decline to values below 5 mg/l is projected in the uppermost channel sections in late autumn.

12. Under postulated 1979 and long-term BOD_5 loading conditions, substantial improvement in DO levels throughout the lake is projected. Potential problems are only indicated in the uppermost channel segments, where levels slightly below 5 mg/l may be seen. It should be kept in mind, however, that the model provides only daily average concentrations, and cannot

predict the range of diurnal variation about that average. Furthermore, these calculations assume no instream nitrification. The results are to be considered preliminary, as the BOD-DO portion of the eutrophication model is uncalibrated. Additional insight has been obtained in this study through the use of the modified Trinity River model, which is discussed below.

Trinity River Model Studies of Dissolved Oxygen in the Lake Headwaters

13. The mathematical model of the Trinity River which had been developed for the TRA in 1974 was recalibrated from its headwaters to near the proposed damsite using comprehensive water quality data collected recently. This model framework is the basis for the evaluation of the potential impact of the lake on the Trinity River. The geometry relationships for the reach to be affected by backwater from the lake were modified to allow the simulation of dissolved oxygen profiles with and without the lake.

14. BOD_5 and ammonia nitrogen point source loads in the Dallas/Fort Worth area were estimated for 1980 and 1990 conditions. Projected 1980 discharge volumes were associated with $BOD_5/TSS/NH_3$-N levels of 10/15/10 mg/l. Projected 1990 discharge volumes were associated with 10/15/10 mg/l and with 5/5/3 mg/l. Dissolved oxygen profiles in the upper Trinity River from Dallas through the headwaters of the lake were calculated under steady state low flow, summer conditions for each of the three loading conditions. Profiles were developed with and without instream nitrification of the ammonia. For comparison, profiles were also calculated based on the existing geometry.

15. Projected 1980 and 1990 DO profiles in the modified Trinity River model indicate a reduction of between 1.5 and 3.0 mg/l in the headwaters of the proposed lake if the dam were constructed as compared with conditions in the river if the dam were not constructed. These results are projected to occur during low flow summer conditions.

16. Whether nitrification will occur in the Trinity River downstream of advanced waste treatment plants is uncertain. The results indicate a signficant difference in the calculated DO in the lake headwaters with and without instream nitrification. The 1990 loadings at effluent concentrations of 10 mg/l BOD_5 and 10 mg/l NH_3-N would cause a DO depression to less than 1 mg/l in the headwaters with instream nitrification and 4 mg/l without. Further, for advanced treatment to 5 mg/l BOD_5 and 3 mg/l NH_3-N, these DO levels would be approximately 3 mg/l with instream nitrification and 4.5 mg/l without.

Trinity River Model Studies of Dissolved Oxygen Downstream of the Dam

17. An evaluation of dissolved oxygen conditions downstream of the proposed dam was prepared. A one-hundred mile reach of the river was examined using a section of the previously developed TRA model. In order to investigate the general recovery characteristics of the river to loads carried in the dam release water, six combinations of dissolved oxygen (DO) and ultimate oxygen demand (UOD) concentrations in the release water were applied under each of the two flow conditions. This provided an indication of the sensitivity of the river DO profile to the DO and UOD in the release water.

18. The Trinity River downstream of the damsite appears to recover slowly from dissolved oxygen depression. Therefore, the river will be sensitive to the amount of oxygen-demanding material present in the release water and to the dissolved oxygen deficit of the water. If the oxygen demand in the water is low, such as an ultimate oxygen demand (UOD) of 5 mg/l, the minimum DO in the river will be at the release point itself. In this case, to meet a stream standard of 5 mg/l, the release water DO concentration should be 5 mg/l or slightly greater. If higher levels of oxygen demanding material are present, such as a UOD of 15 mg/l or greater, release water DO levels in excess of 5 mg/l would be needed to protect against violation of the stream standard.

CHAPTER II
INTRODUCTION

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INTRODUCTION

This report summarizes Phase II of a water quality study of Lake Livingston and the proposed Tennessee Colony Lake. The sites of these reservoirs are located on the main stem of the Trinity River, Texas. The previous Phase I effort[1] investigated the projected eutrophication conditions of the final configuration of the Tennessee Colony Lake with a conservation pool elevation of 275 feet. The present Phase II effort has projected conditions for an interim pool configuration with a conservation pool elevation of 240 feet. Plate 1 presents a map of this configuration.

The following sections of this chapter will provide introductory material briefly reviewing the Phase I work and outlining the purpose and scope of the Phase II work.

A. Summary of Phase I Effort.

In the initial effort, a eutrophication model was developed for Lake Livingston, an existing reservoir approximately 213 river miles downstream of the location of the proposed Tennessee Colony Lake dam. Chlorophyll 'a' was selected as an indicator of algal growth. This model, which tracked suspended solids and nutrients through the lake during an entire year in order to calculate chlorophyll 'a' levels, was calibrated using 1975 data and validated using 1976 data. This procedure produced appropriate values for various kinetic parameters such as decay rates, settling rates and dispersion rates. A similar model structure was then developed for the final configuration of the proposed Tennessee Colony Lake in which the Lake Livingston kinetic parameters were used. Yearly profiles of chlorophyll 'a' were then projected for Tennessee Colony Lake for two distinct flow regimes.

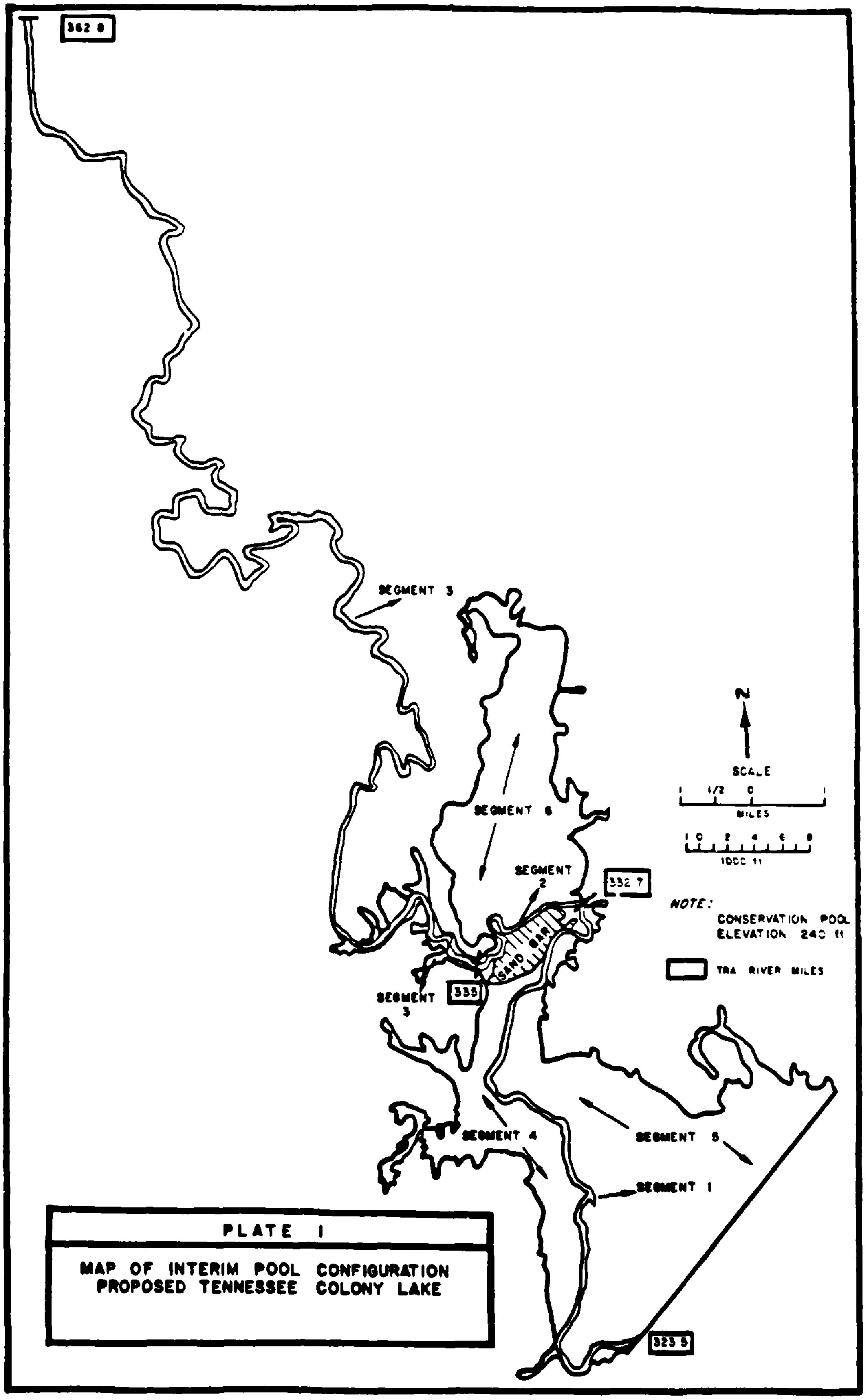

PLATE I

MAP OF INTERIM POOL CONFIGURATION
PROPOSED TENNESSEE COLONY LAKE

B. Purpose of Phase II Effort.

In the Phase II study, a similar model was constructed for a smaller interim pool for which the kinetic parameters developed in Phase I were used. This model was used to project water quality conditions in the interim pool. As in the previous effort, suspended solids and nutrients were tracked through the reservoir and concentrations of chlorophyll 'a' throughout the year were calculated. In addition, calculations of dissolved oxygen levels throughout the year were made. This portion of the model is uncalibrated as it was not included in the original Lake Livingston model.

A second area of concern in the Phase II effort was the potential impact of the Tennessee Colony Lake on water quality in the Trinity River. Two river dissolved oxygen models were developed to investigate this impact: one for the upper Trinity, including the headwaters of the Tennessee Colony Lake, and one for the portion of the river extending 100 miles downstream of the dam. These models were applied primarily to investigate projected dissolved oxygen conditions for conditions for steady state, low flow summer conditions. This low flow summer period generally represents the most critical period of extended depressed dissolved oxygen due to higher reaction rates, reduced DO saturation, less dilution water, and lowered stream velocities.

Chapter III of this report will discuss the results of the Tennessee Colony eutrophication model; Chapter IV will discuss the results of the two Trinity River water quality models.

CHAPTER III

TENNESSEE COLONY LAKE EUTROPHICATION

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TENNESSEE COLONY LAKE EUTROPHICATION

A lake eutrophication model was constructed for the interim configuration of the proposed Tennessee Colony Lake. As in the models developed for Lake Livingston and the final configuration of Tennessee Colony Lake, which are discussed in the Phase I report,[1] chlorophyll 'a' is used as an indicator of algal growth, a chief measure of eutrophication. Projections of chlorophyll levels throughout the year are presented for two annual flow regimes.

In addition, simulations of BOD-DO conditions in the interim pool were performed. This additional BOD-DO model was constructed only for Tennessee Colony Lake and was not included in the previous 1975 and 1976 Lake Livingston calibration and validation.

The following sections of this chapter will describe the computational framework of the models, review the geometry, segmentation and transport mechanisms used for projection purposes, and present the results of projections made using the models.

A. Description of Model Framework.

The eutrophication model employed in this study was developed as a practical engineering tool to allow for the inclusion of the major conditions influencing phytoplankton growth. The model utilizes a growth relationship which includes the major physiological factors which in most cases dominate the algal growth relationship. Growth is related to the temperature of the water body, the available sunlight, suspended solids concentrations, and the concentrations of the major nutrient forms which can be directly utilized by algae. Each of these controlling elements interacts in defining the algal growth rate.

Nutrient concentrations are in turn related to changes in incoming loads and to algal uptake.

The eutrophication model is simply a computational framework within which these complex interrelationships can be handled simultaneously. The basis of the model is a series of conservation of mass equations which relate the variables of concern to each other and also to the boundary loading conditions. The mass conservation equations which result from this formulation are partial differential equations in the time and space variables. In order to implement the solution of such equations on a computer, it is convenient to express them in terms of finite differences. For the spatial variables, this corresponds to dividing the water body into a series of segments or cells which are chosen so that the assumption of spatial homogeneity within each segment is reasonable. A typical conservation of mass equation used in the model for concentration c_{ij} of substance i in segment j has the general form:

$$V_j \frac{dc_{ij}}{dt} = \sum_k Q_{kj} c_{ik} + \sum_k E'_{kj} (c_{ik} - c_{ij}) + S_{ij} \qquad (1)$$

where V_j is the segment volume; S_{ij} is the net source of substance i in segment j; E'_{kj} is the bulk rate of transport of c_{ik} into and c_{ij} out of segment j for all segments k adjacent to segment j; and Q_{kj} is the net advective flow rate between segments k and j. Numerical integration of these equations gives the daily distribution of the concentrations in each of the spatial segments of the model.

A detailed description of model kinetics has been provided as Appendix B to the Phase I report.

B. Model Geometry.

The Tennessee Colony Lake model for the interim pool is shown in Plate 1 and schematically in Figure 1. The model includes the area of the proposed impoundment that would be covered at the conservation pool elevation of 240 feet above sea level, some 15,100 acres. The pool will contain a volume of 109,900 acre feet or 4,787 million cubic feet. Lake level is assumed to remain constant throughout the year; that is, flow out equals flow in.

Two model configurations have been developed to represent two alternative approaches to the transport and mixing characteristics of the proposed impoundment. The first configuration consists of six segments. Three segments correspond to the deep, existing river channel areas of the impoundment; three segments are used to describe the large, shallow areas adjacent to the deeper river channel. The second configuration assumes the impoundment to be a single completely-mixed volume, with total lake volume and average lake depth.

The geometries of the model segments for both configurations are presented in Table 1. Segment interconnections are defined by characteristic lengths, dispersion coefficients, and interfacial cross-sectional areas, also presented in Table 1.

C. Transport Regimes.

A basic requirement for a modeling effort based on conservation of mass is an adequate representation of the mass transport mechanisms in the study area. The representation chosen is based on the advection-dispersion formulation of mass transport. Advective mass transport is accomplished by the average unidirectional net motions of the water. Dispersive mass transport is accomplished by the mixing motions of the water body such as the smaller scale circulations.

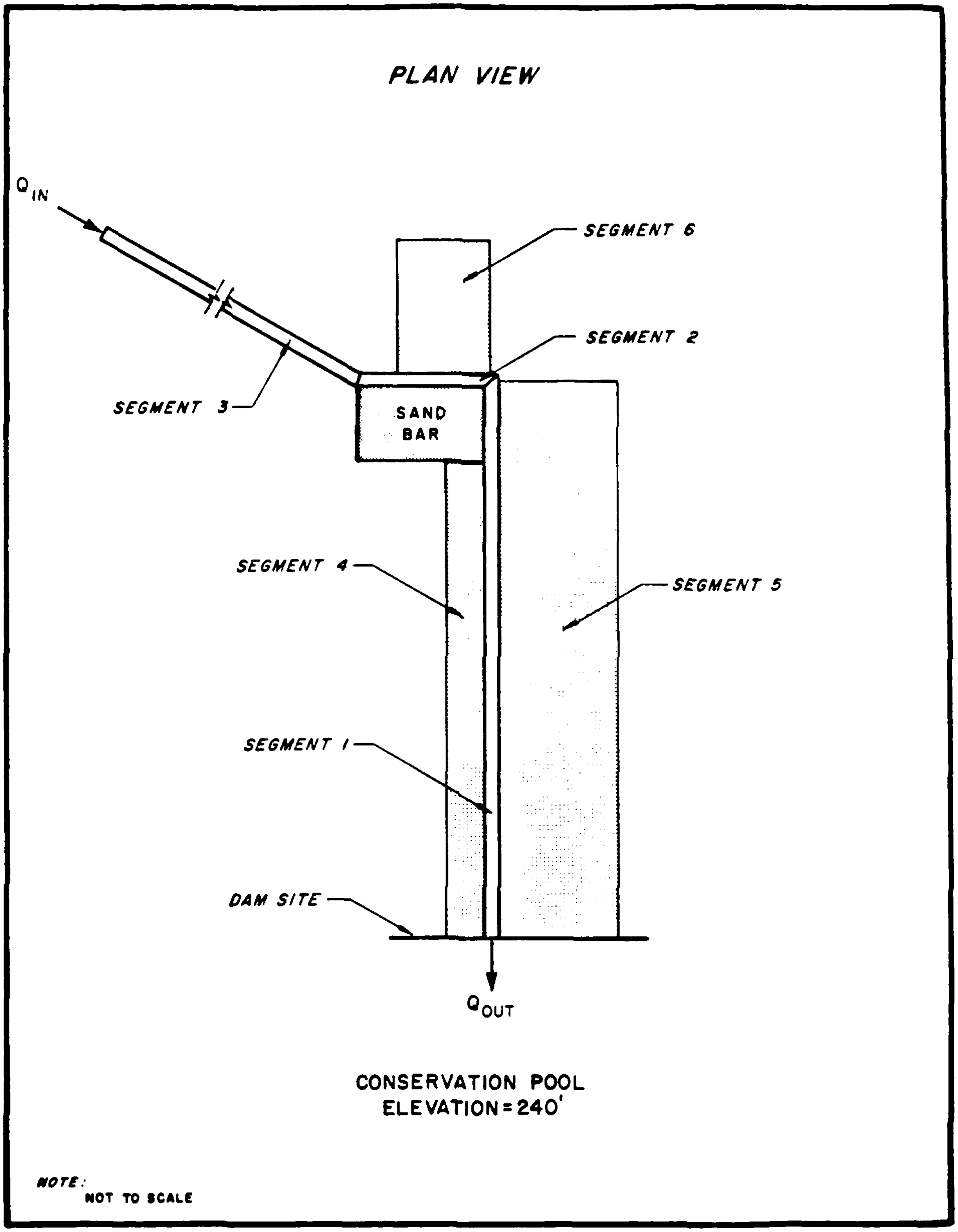


FIGURE 1
TENNESSEE COLONY LAKE INTERIM POOL CONFIGURATION MODEL SCHEMATIC

TABLE 1

TENNESSEE COLONY LAKE INTERIM POOL GEOMETRY

SEGMENT GEOMETRY

SEGMENT	VOLUME ($10^6 ft^3$)		SURFACE AREA ($10^3 ft^2$)		MEAN DEPTH (ft)
1	491.9		18.0		27.3
2	40.7		2.22		18.3
3	618.1		42.5		14.5
Channel Segment Subtotal		1,150.7		62.7	(18.4)
4	807.4		115.4		7.0*
5	2,124.1		303.4		7.0*
6	705.0		176.2		4.0*
Shallow Segment Subtotal		3,636.5		595.0	(6.1)
Reservoir Total		4,787.2		657.7	(7.3)

INTERFACE GEOMETRY

INTERFACE	WIDTH (ft)	DEPTH AT INTERFACE (ft)	CROSS-SECTIONAL AREA (ft^2)	LENGTH I (ft)	LENGTH J (ft)
0-1	180	42.0	7,564	48,000	48,000
1-2	277	23.5	6,502	48,000	12,000
2-3	280	18.7	5,232	12,000	147,500
3-0	112	9.9	1,109	147,500	147,500
1-4	41,000	12.5	512,500	229**	3,000
1-5	48,000	12.5	600,000	229**	9,000
2-6	8,000	7.0	56,000	279***	11,400

* Estimated
** Average of 0-1 and 1-2 width
***Average of 1-2 and 2-3 width

Flow regimes into Tennessee Colony Lake were determined based on analyses of flow estimates prepared by the Corps of Engineers(2). The Corps of Engineers has presented forty-seven years of monthly flows at Tennessee Colony adjusted for existing and authorized projects in the Trinity River basin. Several recurring patterns are evident upon examination of the annual hydrologic record. First, the summer period of July, August, and September typically has low flows, generally less than 650 cfs at Tennessee Colony. Second, annual hydrology can be described on the basis of the magnitude of May flows. The characterization of an annual record as having either a high or a low May flow is a prominent feature of the data. Figures 2 and 3 present examples of years which have high monthly average flows in May and those years having low flows in May. Figure 2 presents Trinity River flows at Tennessee Colony for the six years in the record with the lowest average monthly May flows. Figure 3 presents the Trinity River flows at Tennessee Colony for the six years in the record with the highest May flows. In each instance logarithmic averages of the monthly flows are calculated to produce a composite annual profile which is indicated on the figures. The log averaging process is used since the intent of the analysis is to show patterns rather than an average flow. The log average tends to damp out extremes in the data and thus is more indicative of average trends.

These two flow patterns, that is, years with high flows in May and years with low flows in May, are representative of the majority of annual patterns in the record and present limits which are used to bracket flows which can reasonably be expected in the future. The log averages

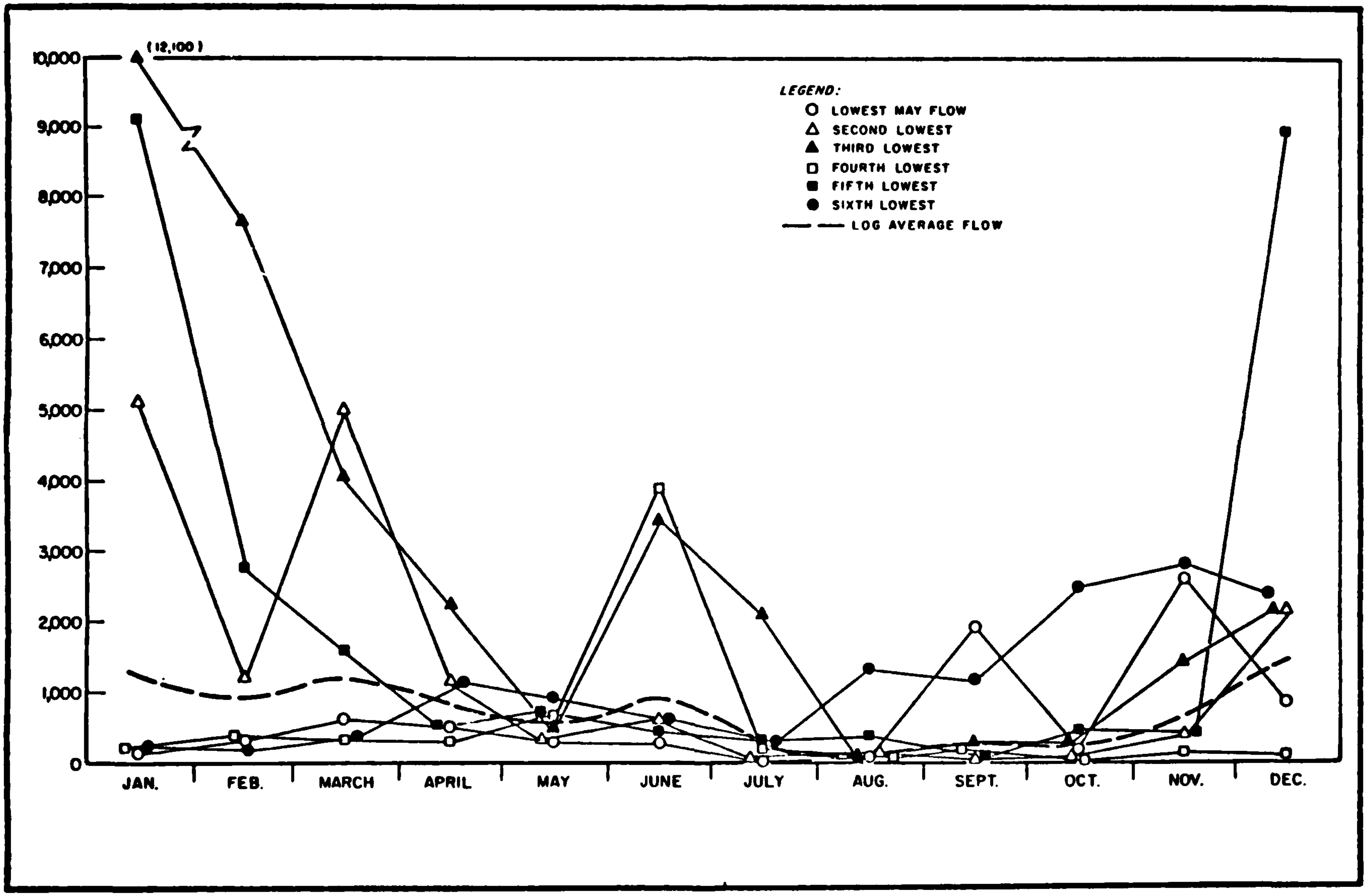


FIGURE 2
MONTHLY AVERAGE FLOWS AT TENNESSEE COLONY, LOW MAY FLOW YEARS

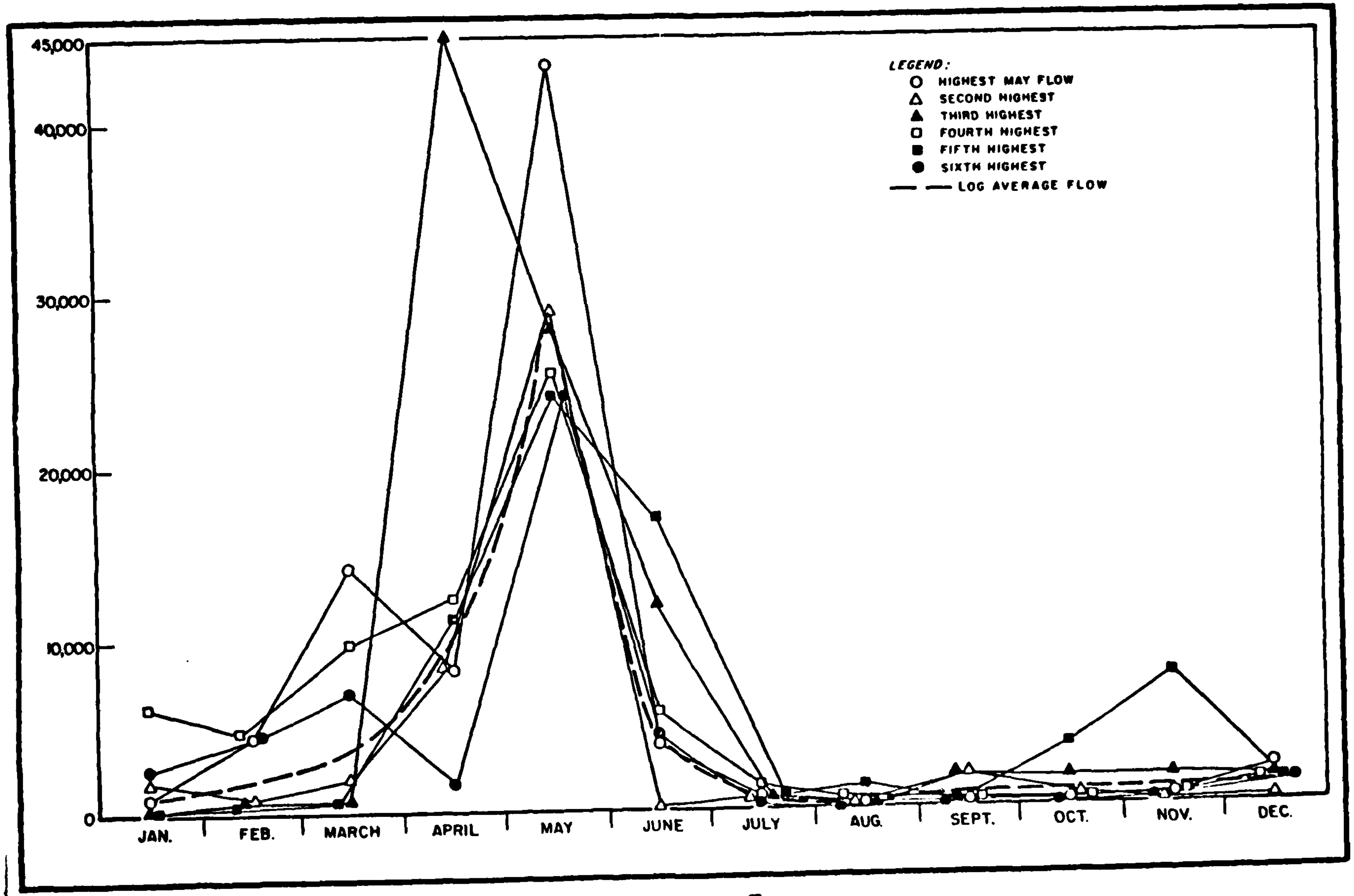


FIGURE 3
MONTHLY AVERAGE FLOWS AT TENNESSEE COLONY, HIGH MAY FLOW YEARS

of the monthly flows are used for projection purposes in the Tennessee Colony Lake model, as discussed in subsequent sections of this chapter.

Flow is routed through the main channel segments of the six-segment model, and in and out of the completely-mixed model. Constant segment and reservoir volumes are assumed, i.e., whatever flow volume enters from up river is discharged at the dam.

One measure of sensitivity to flow conditions is hydraulic detention time. Hydraulic detention time, defined as volume divided by flow, is the average time required for water to pass through a volume. For conservative substances, approximately two detention times are necessary for a completely-mixed volume to approach a new equilibrium condition. Hydraulic detention times based upon the total interim pool volume of Tennessee Colony Lake range from over nine months at low flows below 200 cfs to less than six days at flows above 10,000 cfs. Average low flow year detention time is approximately 2.5 months; high May flow year detention time is on the order of 13 days. At peak high flow during the high May hydrology of 28,300 cfs, hydraulic detention time decreases to approximately two days. These numbers can be understood as follows: at low flows, even large changes in influent concentrations will have minor effects on the concentration of the completely-mixed volume for most time frames; at higher flows, changes in influent concentrations have increasingly greater impacts on completely-mixed volume concentrations.

Horizontal dispersion coefficients are used to provide mixing between the deep channel segments and the shallow segments of the flats. A range of transport coefficients was examined since the Tennessee Colony Lake interim period

pool configuration and volume are quite different from those of the Lake Livingston reservoir which was used for model calibration. Results were produced using a value of 0.1 mi^2/day, the value used in the Lake Livingston model and the Phase I Tennessee Colony model. The sensitivity of the model results to this value was examined by reproducing calculated concentrations using a value of 0.002 mi^2/day. This value is consistent with those typical of small and medium-sized rivers. Comparison of the results obtained using this range of values, plus the results from the completely-mixed volume assumption, should provide an understanding of the sensitivity of model projections to transport coefficients.

D. Loading Conditions.

For the purposes of this study, all nutrient, BOD and suspended solids loadings to Tennessee Colony Lake are assumed to be associated with Trinity River inflows to the impoundment. Other sources, such as Richland Creek, Chambers Creeks, and Tehuacana Creek, join the Trinity River above the main body of the interim pool. No direct point or nonpoint source discharges are postulated at the present time.

An in-depth analysis of constituent concentrations in the Trinity River at Rosser, approximately 60 miles upstream from the impoundment, was performed as part of the Phase I effort. The relationships between flow and concentration were examined for chlorophyll 'a', suspended solids, nitrogen forms, phosphorus forms, and BOD_5; with the exception of chlorophyll 'a', rating curves were developed for all constituents which serve to provide values of concentration for given flows. Daily loadings via the

Trinity River inflow were input to the Tennessee Colony Lake model by selecting the appropriate concentrations from these curves.

1. Rating Curves. Analysis of the concentration data indicated a strong positive correlation between suspended solids and flow and strong negative correlation between BOD_5, nitrogen series, and phosphorus series concentrations and flow. Little variation in chlorophyll 'a' levels was shown. The trends of the chemical constituents are shown in Figures 4 and 5.

Figure 4 presents values of total nitrogen, ammonia nitrogen, nitrate plus nitrite nitrogen, and organic nitrogen versus river flow at Rosser. Figure 5 presents values of total phosphorus, BOD_5, and total suspended solids versus flow for the same location. Data are from published U.S. Geological Survey (USGS) records for the period 1971 through 1975[3]. Where lines are indicated on the figures, the lines are trend lines, not regressions.

Total nitrogen and total phosphorus concentrations exhibit similar behavior with flow. High total nutrient concentrations are characteristic of low river flows: concentrations tend to decrease as flow increases, apparently due, at least in part, to dilutional effects. Further, there appears to be a possible background level concentration even at higher flows.

These patterns can be explained as follows: at low flow, the major portion of Trinity River flow is composed of treated effluent from the Dallas-Fort Worth Metroplex; as flow increases due to land runoff, concentrations decrease due to dilution with lower concentration waters, until at high flows, the river concentrations approach values typical of those expected in nonpoint source runoff for east Texas[4,5,6]. In particular, at Rosser, total

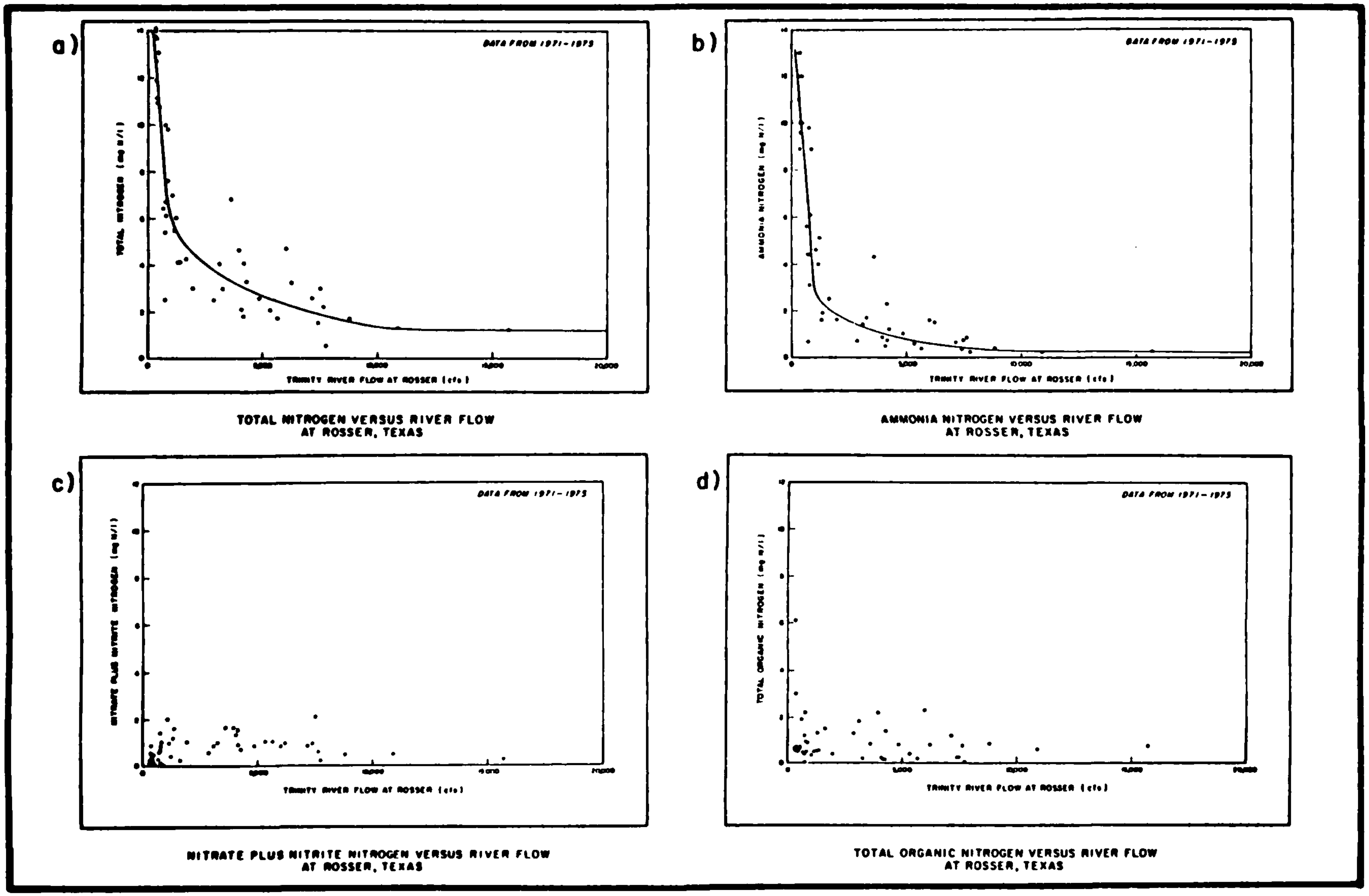
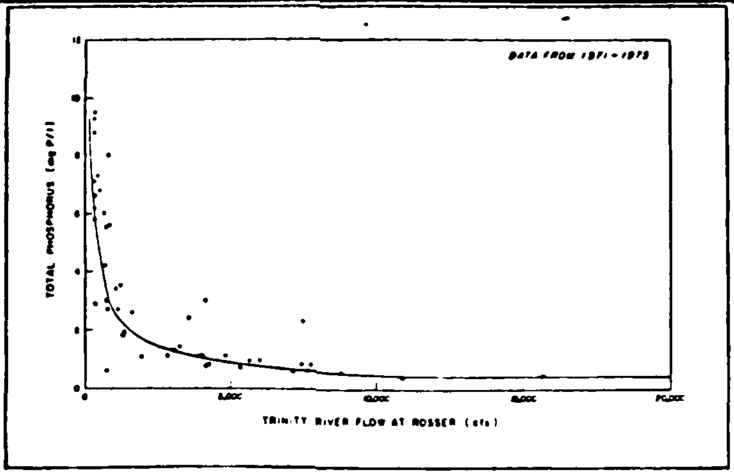


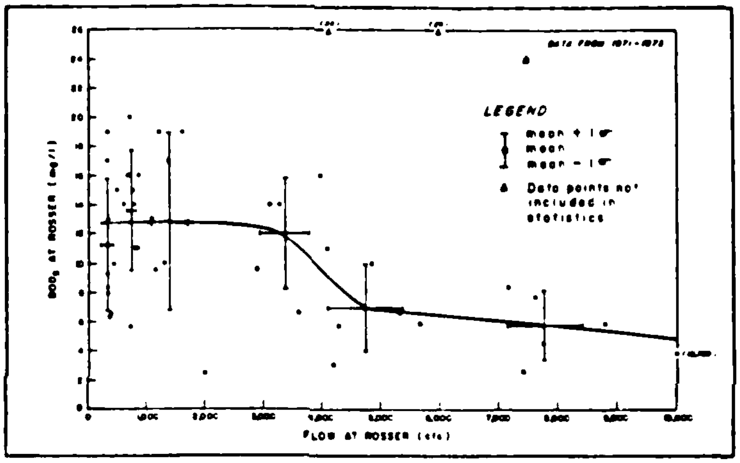
FIGURE 4
MEASURED NITROGEN SERIES CONCENTRATIONS VERSUS RIVER FLOW
AT ROSSER, TEXAS

a)



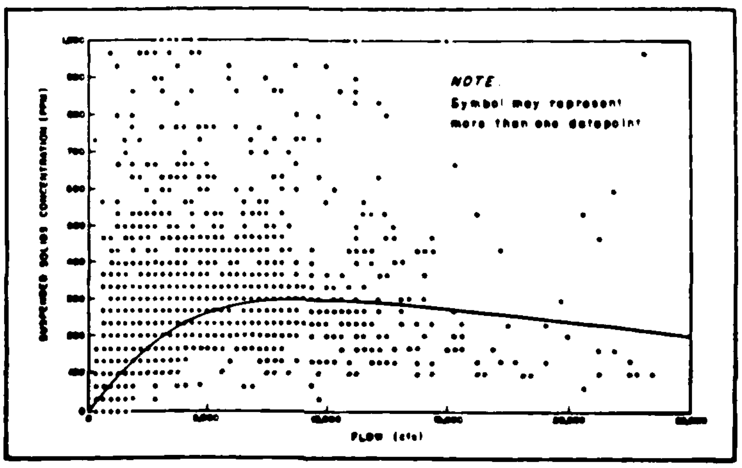
TOTAL PHOSPHORUS VERSUS RIVER FLOW AT ROSSER, TEXAS

b)



BOD_5 VERSUS RIVER FLOW AT ROSSER, TEXAS

c)



TOTAL SUSPENDED SOLIDS VERSUS RIVER FLOW AT ROSSER, TEXAS

FIGURE 5

TOTAL PHOSPHORUS, BOD_5, AND TOTAL SUSPENDED SOLIDS CONCENTRATIONS VERSUS RIVER FLOW AT ROSSER, TEXAS

nitrogen concentrations range from a high value of approximately 15 mg/l at low flows to concentrations of 4 to 2 mg/l at moderate flows (2,000 - 6,000 cfs), to approximately 1.2 mg/l at flows above 10,000 cfs. Total phosphorus concentrations range from a high of about 9 mg/l at low flows, to concentrations of 4 to 0.7 mg/l at moderate flows, to approximately 0.5 mg/l at flows above 10,000 cfs.

The individual nitrogen species are also of interest both for an understanding of what is occurring in the system and because a breakdown by nitrogen species is necessary for model input. At Rosser, ammonia nitrogen contributes the major fraction of the total nitrogen concentration, and consequently, the ammonia nitrogen and the total nitrogen concentrations range from about 13 mg N/l at low flows to concentrations of 2.0 to 0.5 mg N/l at moderate flows to approximately 0.3 mg N/l at higher flows.

Conversely, nitrate plus nitrite nitrogen and organic nitrogen concentrations exhibit no such flow dependence at Rosser. Figure 4 presents nitrate plus nitrite nitrogen at Rosser as a function of flow for those data having synoptic measurements for ammonia and organic nitrogen. The data are fairly constant at all flows, and have a mean value of 0.8 mg N/l. Figure 4 also presents total organic nitrogen at Rosser as a function of flow. While more scattered than the nitrate plus nitrite data, the shape is similar, with no discernible flow related effects present. The mean value for total organic nitrogen at Rosser is 0.9 mg N/l.

Figure 5 presents BOD_5 measurements at Rosser versus river flow. While data scattering is evident, a statistical grouping of measurements indicates a relatively constant mean BOD_5 concentration of 12.8 mg/l until river flows exceed 3,000 cfs. Mean BOD_5 concentrations decrease

markedly above 3,000 cfs. BOD_5 data at flows above 5,000 cfs are sparse.

It should be recognized that these BOD_5 data relate to the total oxygen demand of a sample during a 5-day incubation period. As such, the measurements include the oxygen utilized by any of several mechanisms, including bacterial decomposition and algal respiration. As bacterial decomposition of carbonaceous material is the primary process of interest in the BOD_5 measurement, the effects of algal respiration should be discounted. When measurements of algal biomass are made concurrent with BOD_5 measurements, it is possible to estimate the fraction of the measured BOD_5 which is due to algal respiration. The measured BOD_5 values can then be adjusted to reflect only bacterial activity. No such concurrent measurements are available in the present study; these BOD_5 values therefore are not totally reflective of the available BOD_5 entering the Tennessee Colony Lake.

Figure 5 presents total suspended solids concentration versus river flow at Rosser. These data are daily measurements covering the period 1971 to 1975 and are available from the Texas Natural Resources Information System. The data are variable, but show increasing concentration with flow up to some point above which concentration appears to decrease.

2. Boundary Conditions. The nutrient, BOD_5, and total suspended solids rating curves are applied to the high or low May annual hydrologic regimes to provide loading information to the eutrophication model. This is done via model boundary conditions. For a particular daily flow, an appropriate concentration is selected from the rating curve. This concentration is applied at the model boundary to input the proper mass of material to the model.

An exception to this procedure is the determination of chlorophyll 'a' boundary conditions. Inflow levels were set to a constant 5 μg/l for all flow conditions. It was determined during the Lake Livingston reservoir calibration and validation procedure that data regarding higher chlorophyll 'a' concentrations in the Lake Livingston inflow notwithstanding, a constant boundary condition would be adequate to reproduce observed reservoir chlorophyll 'a' concentrations. This results from a combination of effects. First, because of the magnitude of the algal growth and death rates, phytoplankton growth kinetics in the reservoir, rather than chlorophyll 'a' influent concentrations, determine algal levels in the lake for most flow conditions. Second, with regard to a strict mass balance of materials, the mass of chlorophyll 'a' entering the reservoir is generally small and does not appreciably alter reservoir concentrations due to the large volume of the lake. This relative insensitivity to the chlorophyll 'a' boundary condition is fortuitous since it obviates the need for precise chlorophyll 'a' boundary concentration determination.

E. Initial Conditions.

It is necessary in a time variable simulation to supply initial concentration values for each system variable in each model segment as a starting point for computations. The choice of these initial conditions will have an effect on subsequent computations until such time as the initial conditions have "washed out" of the system. These are called transient effects. In terms of the previous discussion of hydraulic detention time, approximately two detention times are required for transient effects to be minimized.

Ideally, initial conditions are either chosen from observed data or the model is run for several years of simulation to wash out assigned initial conditions. Since in the present case, the latter method requires additional assumptions as to the repetitiveness of annual hydrologies, model initial conditions in all cases were assigned, as best estimates, from the rating curves.

F. Model Projections.

All of the above factors were incorporated into the eutrophication model of the interim pool of the proposed Tennessee Colony Lake. The model was used to project annual water quality trends under the two idealized flow regimes. The single-segment, completely-mixed model projected values of chlorophyll 'a', an indicator of algal biomass, under the high May and low May flow regimes. The six-segment model projected values of chlorophyll 'a' under both flow regimes, once using a moderate horizontal dispersion rate (0.1 mi^2/day) and then using a lower bound value (0.002 mi^2/day). In addition, projections of dissolved oxygen were produced using the six-segment configuration under various flow and loading conditions. These projections examine the expected impoundment responses for changes in hydrologic regimes and the sensitivity of the model to assumptions regarding transport within the lake. It must be emphasized that dissolved oxygen projections from the eutrophication model are only preliminary estimates since dissolved oxygen model kinetics are uncalibrated for the lake model. The estimates can however be useful in the evaluation of the proposed project and in the analysis of specific designs and operation procedures. Table 2 summarizes the model projections produced for the interim pool.

TABLE 2

SUMMARY OF INTERIM TENNESSEE COLONY LAKE MODEL RUNS

RUN NO.	CONFIGURATION	FLOW REGIME	DISPERSION RATE (mi^2/day)	LOADING CONDITION*	CONSTITUENT PROJECTED
1	completely mixed	low	-	all present loads	chlorophyll 'a'
2	completely mixed	high	-	all present loads	chlorophyll 'a'
3	6-segment	low	0.002	all present loads	chlorophyll 'a'
4	6-segment	high	0.002	all present loads	chlorophyll 'a'
5a	6-segment	low	0.1	all present loads	chlorophyll 'a' dissolved oxygen
5b	6-segment	low	0.1	present upstream loads only	dissolved oxygen
6a	6-segment	low	0.1	all 1979 loads	dissolved oxygen
6b	6-segment	low	0.1	1979 upstream loads only	dissolved oxygen
7a	6-segment	low	0.1	all long-term loads	dissolved oxygen
7b	6-segment	low	0.1	long-term upstream loads only	dissolved oxygen
8a	6-segment	high	0.1	all present loads	dissolved oxygen
8b	6-segment	high	0.1	present upstream loads only	chlorophyll 'a' dissolved oxygen
9a	6-segment	high	0.1	all 1979 loads	dissolved oxygen
9b	6-segment	high	0.1	1979 upstream loads only	dissolved oxygen
10a	6-segment	high	0.1	all long-term loads	dissolved oxygen
10b	6-segment	high	0.1	long-term upstream loads only	dissolved oxygen

Note: No nitrification of ammonia nitrogen.

* "Upstream loads only" indicates suppression of algal impact on production and demand of oxygen.

1. Chlorophyll 'a'. Chlorophyll 'a', as a measure of phytoplankton biomass, is the model variable by which comparisons of lake trophic state are made. It is a direct measure of the quantity of photosynthetic plant pigments present, and can be related directly to oxygen production. Discussions of chlorophyll 'a' as an indicator of trophic level, water quality, and beneficial water uses have been presented in previous reports[1,7]. Many studies have used chlorophyll 'a' as an indicator of primary productivity or lake eutrophic state[8,9,10,11,12,13]. Interpretation of the impact of algal levels is somewhat subjective. There is no universal standard for acceptable levels of chlorophyll 'a' and the impact of this parameter must be tied to local water use objectives. It remains for the appropriate planning and regulatory agencies to determine desirable concentration levels.

As indicated in Table 2, six projections of chlorophyll 'a' were performed. Two projections are based on the completely-mixed configuration and the remaining four for the six-segment model.

a. Completely-Mixed Configuration. Figure 6 presents chlorophyll 'a' concentration projections for the interim pool configuration of Tennessee Colony Lake assuming the entire impoundment is completely mixed. Calculations are presented for both low and high flow hydrologies.

Chlorophyll 'a' concentration levels between 40 to 80 μg/l are projected for most of the low flow year. Somewhat different algal behavior is projected for the high flow year hydrology. Impoundment chlorophyll 'a' concentrations are projected to increase early in the year and then decrease during the high flow period. The lack of algal growth during the high flow portion of the year is due to a combination of light limitation and detention

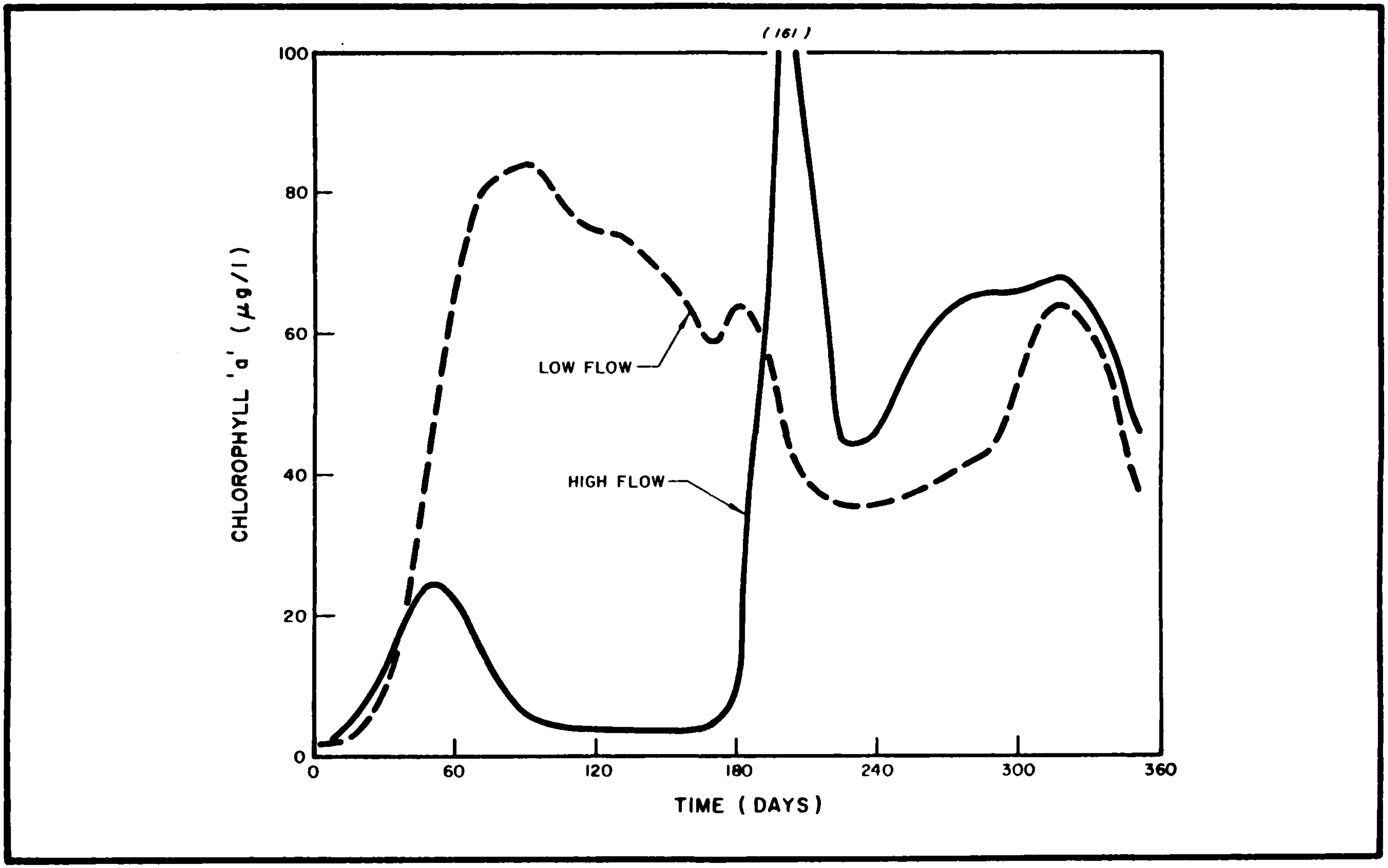


FIGURE 6
CHLOROPHYLL 'a' CONCENTRATION PROJECTIONS
COMPLETELY MIXED CONFIGURATION - EFFECT OF FLOW REGIME

time effects. Flow related increases in influent suspended sediments cause an increase in impoundment suspended solids concentrations, causing a corresponding decrease in available light for phytoplankton growth. This decrease causes a decline in the phytoplankton growth rate, which of itself or in combination with the flow through the impoundment removing material from the impoundment, prevents net increases in algal levels. This occurs even though nutrients are plentiful.

As flow decreases, around day 160, light penetration increases, increasing the growth rate; impoundment residence time also increases due to decreasing flow, thus allowing time for growth to occur. The result is a rapid increase in chlorophyll 'a' concentrations to levels over 150 µg/l. At this point, available inorganic nutrients are exhausted and the algal population declines to a level that can be sustained by nutrient inflow to the impoundment and by nutrient recycle. Nutrient recycle involves the respiration and death of algal cells to non-living organic nutrients, and the subsequent conversion to inorganic nutrients available for further algal growth. This combination of inflow and recycle is calculated to allow population levels of 40 to 60 µg/l chlorophyll 'a' to be sustained during low flow periods.

b. <u>Multi-Segment Configuration</u>. In an effort to address the sensitivity of model calculations to assumptions regarding impoundment dispersional transport, the multi-segment model configuration is used for projections and three deep areas. The deep areas correspond to the existing river channel running through the proposed lake area. River flow is assumed to be confined to these segments. Transport between deep and shallow segments is limited to dispersional mixing.

Two values of the horizontal dispersion coefficient are considered in the analysis. The first calculation employs a value consistent with that used in the Lake Livingston model calibration and validation, and for the projections performed for the original Tennessee Colony Lake study. The second calculation reduces the dispersion coefficient to a level associated with small or medium-sized rivers. The results of these computations are shown in Figure 7 for the low May flow hydrology and in Figure 8 for the high May flow hydrology.

For low flow hydrology, chlorophyll 'a' concentrations are projected to range from 5 to 100 μg/l. Considering the higher dispersion case, concentrations in Segments 2 and 3, the upper and middle main stem segments, remain relatively low until midsummer (day 150 to 180), at which time substantial growth is projected to occur. This behavior is due to a combination of flow related effects: light limitation of the algal growth rate due to flow related suspended solids, and hydraulic detention time of the segment. No net concentration increase is projected in Segment 3 until such time as the flow through the segment is reduced to very low levels.

The situation in the rest of the impoundment is quite different. Rapid growth is projected in the remainder of the reservoir with chlorophyll 'a' levels remaining between 20 and 100 μg/l. In general, growth occurs in the shallow areas, Segments 4, 5 and 6, and the algae are dispersed to the deeper channel segments. The shallow areas utilize the nutrients which are brought into the impoundment with the flow and moved to the shallows by dispersion. The effect of the midsummer bloom in Segments 2 and 3 is quite clear in the remainder of the reservoir. The bloom converts inorganic nitrogen to algal cells in Segments 2 and 3, leaving

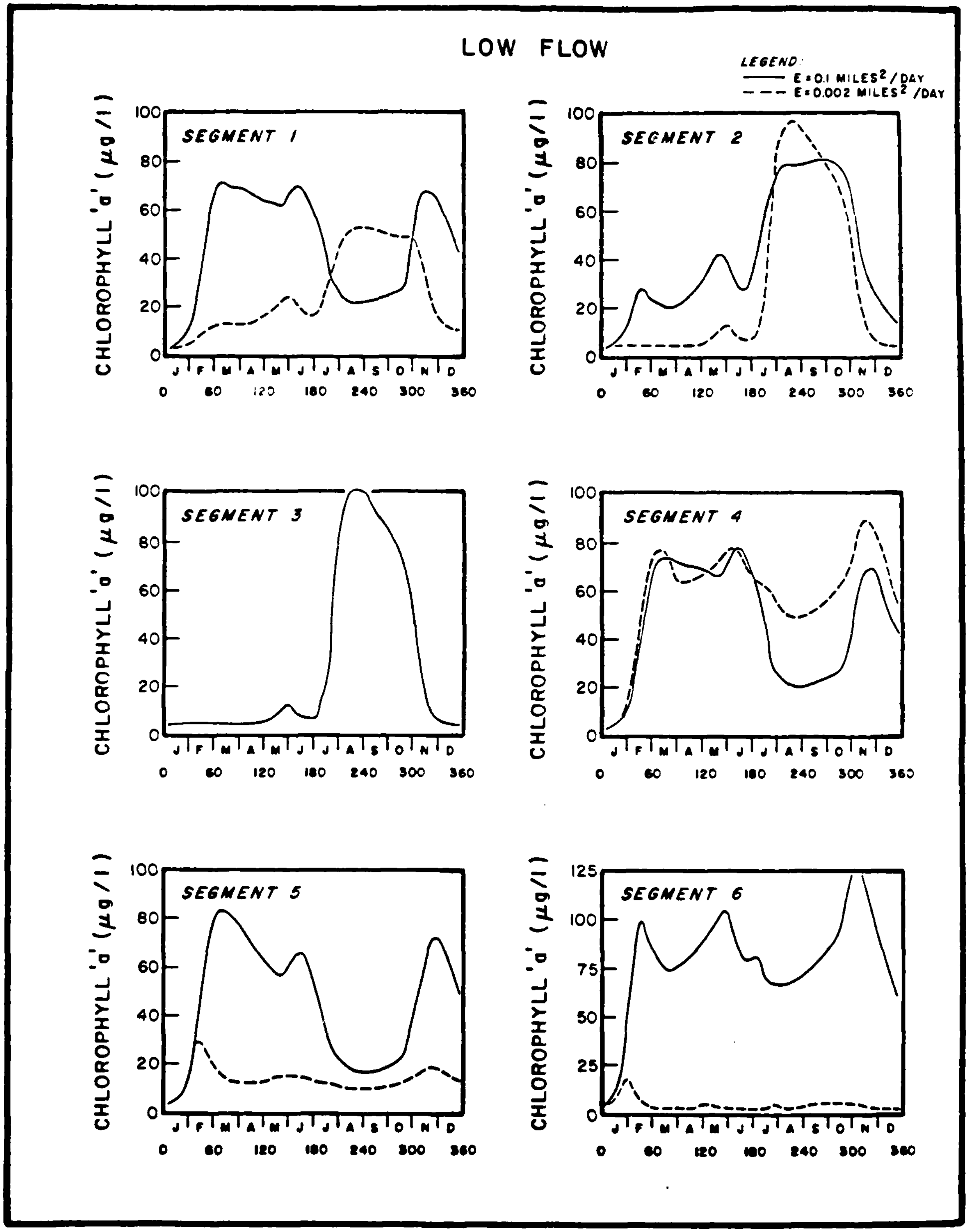


FIGURE 7
CHLOROPHYLL 'a' CONCENTRATION PROJECTIONS
LOW FLOW HYDROLOGY, EFFECT OF DISPERSION

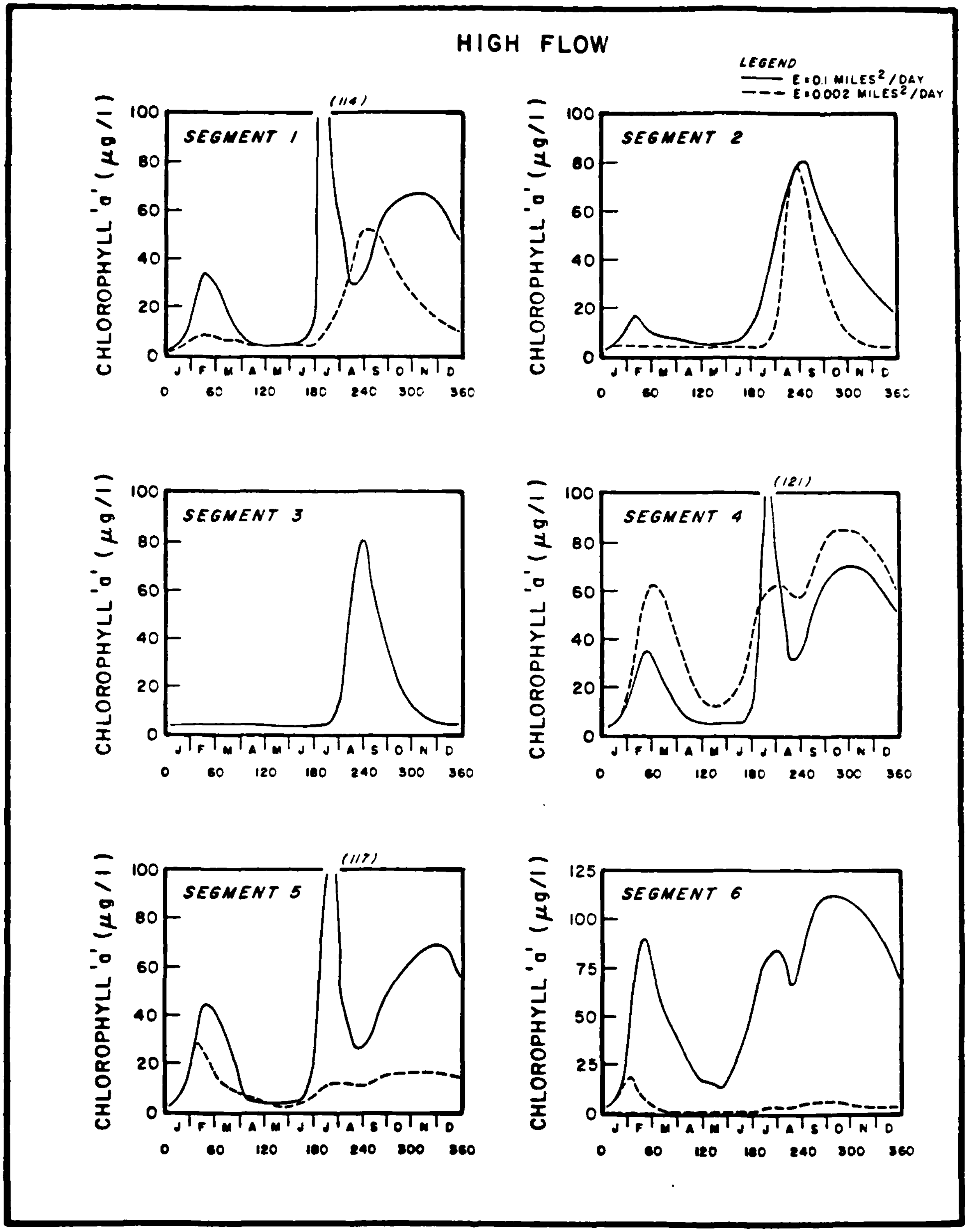


FIGURE 8
CHLOROPHYLL 'a' CONCENTRATION PROJECTIONS
HIGH FLOW HYDROLOGY, EFFECT OF DISPERSION

less available for algal uptake in the lower reservoir. The effect can be seen in the population decreases in Segments 1, 4 and 5 starting at about day 150. As the upstream algal concentrations decline, downstream levels are projected to increase due to the renewed availability of nutrients.

It is noted that the algal chlorophyll 'a' patterns in the lower lake which result under the higher dispersion assumption are quite similar to those projected for the completely-mixed scenario. The situation is markedly different for the lower dispersion assumption.

Projections for the high flow hydrology are presented in Figure 8. Chlorophyll 'a' concentrations are expected to range from the boundary condition of 5 μg/l to peaks of 120 μg/l. Overall impoundment concentrations vary depending upon the level of the dispersion coefficient used in the computations. The behavior in the upper reservoir, Segments 2 and 3, is similar to that for the low flow hydrology. Chlorophyll 'a' concentrations remain low, generally less than 10 μg/l in that area until such time as flows decrease to below 500 cfs. The algal population increases sharply at that time due to increased light penetration and detention times. Concentration peaks of 80 to 120 μg/l are projected in that area. Levels decline thereafter due to increasing flow and turbidity.

As under the low flow hydrology, most growth occurs in the shallow areas of the impoundment, Segments 4, 5 and 6, for the higher dispersion assumption. Nutrients brought into the lake in the main stem segments disperse into the bay segments; the algae produced there then disperse back into the main stem segments. Peak concentrations in the lower lake are 121, 117, and 114 μg/l for Segments 4, 5 and 1, respectively. Population levels peak and then decline to levels that can be sustained by nutrient inflow and recycle. Under the lower dispersion assumption, insufficient nutrients

disperse into the bay segment. The shallows are projected to exhaust inorganic nitrogen concentrations early in the year and not provide the growth and biomass exchange seen in the higher mixing case. The result is a series of quite different and usually lower annual population patterns in the main body of the impoundment. The trends seen in the lower reservoir under the high flow regime are also very similar to those for the completely mixed configuration.

2. Dissolved Oxygen. The time variable water quality models and associated segmentation previously discussed were employed to generate calculated dissolved oxygen profiles for the six-segment model only. The parameters and coefficients employed in the analysis are listed in Table 3. These coefficients represent an estimate of probable appropriate values. The dissolved oxygen computations were developed employing an uncalibrated and unverified model. The results of the analysis should therefore be viewed as preliminary estimates of the anticipated dissolved oxygen levels under projected conditions. These estimates can, however, be employed in evaluation of the proposed Tennessee Colony Lake project and analysis of specific designs and operating procedures.

The basic phytoplankton model framework and values for coefficients and transport terms were employed in the dissolved oxygen analysis. The two flow regimes utilized have been described previously. Existing data on instream BOD and the nitrogen series were analyzed resulting in the rating curves shown in Figures 4 and 5.

The BOD_5 data and the line on the figure represent the use of dissolved oxygen by living phytoplankton during the bottle test in addition to oxidation of carbon associated with point source and other discharges. These two sources of oxygen utilization cannot be separated in the

TABLE 3

COEFFICIENTS EMPLOYED IN THE LAKE DISSOLVED OXYGEN ANALYSIS

COEFFICIENT	SYMBOL	VALUE
Dispersion Rate (mi^2/day)	E	0.1 or 0.001
Dissolved Oxygen Reaeration Rate at 20°C (1/day)	K_a	2.0 ÷ Depth (ft)
BOD_5 Oxidation Rate at 20°C (1/day)	K_r	0.2
Ratio of Ultimate BOD to BOD_5	f_c	1.43
Oxygen to Chlorophyll 'a' Ratio (mg O_2/mg Chl)	a_{OP}	0.133
Phytoplankton Respiration Rate at 20°C (1/day)	K_2	0.1
Phytoplankton Settling Rate (m/day)	ω_p	0.1

NOTE: Coefficients used in the phytoplankton growth and death analysis were developed employing the calibrated Lake Livingston model. System geometry and transport parameters were identical to those employed in the phytoplankton analysis.

standard BOD test procedure. As the model converts dying algae to an oxygen demand separately from the oxidation of non-living BOD_5, inputing these measured BOD_5 values would cause the model to oxidize the algae twice. An estimate of the order of phytoplankton contribution to the measured river BOD can be obtained by consideration of the chlorophyll levels or numbers of plankton present in the sample. Extensive information on these variables is not available. However, the limited available data suggest ranges in equivalent chlorophyll between 20 and 120 μg/l with average levels on the order of 30 to 60 μg/l. The calculated equivalent oxygen demand of this chlorophyll ranges between 2 and 6 mg/l of five day BOD. The chlorophyll contribution to the measured BOD_5 data should be highest in the warmer periods and under low flow conditions. In summary, between one fourth and one half of the measured BOD_5 at Rosser is probably associated with oxidation of living phytoplankton biomass in the BOD bottle. In general, oxidation of the plankton biomass will be upper bounded by the BOD_5 bottle data. If BOD_5 values are not manually reduced before being used as boundary conditions, the dissolved oxygen calculations can be considered conservative and tending to overestimate upstream impacts. An upper bound would be to consider the bottle BOD_5 to be entirely due to algae; normal phytoplankton respiration and growth could be considered a lower bound, requiring a forty percent reduction in the measured upstream BOD to remove algae effects.

There are two levels of waste load reductions being considered for the point sources in the Dallas-Fort Worth area. Under 1979 conditions, it is anticipated that waste treatment plants will be discharging wastewater with 10 mg/l of BOD_5 and 17 mg/l of ammonia nitrogen. Further improvements in waste treatment under consideration for

some future period would reduce effluent concentrations to 5 mg/l of BOD_5 and 3 mg/l of ammonia nitrogen. These two projected effluent sets can be compared to existing regionwide effluent quality which averages approximately 25 mg/l of BOD_5 and 20 mg/l of ammonia nitrogen. It is this existing level of treatment which is reflected in the reported BOD_5 and ammonia nitrogen data previously illustrated in Figures 4 and 5. As the Trinity River is dominated by sewage treatment plant effluents during low flow periods, one method of adjusting the two rating curves to approximate the two future BOD_5 and NH_3-N loading conditions entering the proposed Tennessee Colony Lake is to multiply the curves in Figures 4 and 5 by the ratio of effluent concentrations under future and present conditions. These ratios are summarized in Table 4.

This procedure is more appropriate under low flow conditions, which are critical from the standpoint of dissolved oxygen, as wastewater contributes a significant portion to river flow. As the Trinity River flow increases, nonpoint sources, resuspension, and other phenomena contribute additional BOD_5 and ammonia nitrogen to the river. Thus the reductions in river BOD_5 and ammonia nitrogen tend to be overestimated.

The procedure outlined above includes the BOD_5 contributed by phytoplankton oxidation in the BOD bottle under existing conditions. Therefore, the calculated dissolved oxygen impacts will be conservative estimates tending to yield low projected dissolved oxygen levels.

Projected dissolved oxygen levels over an annual period are presented in Figures 9, 10 and 11 for the low flow regime. Figures 12, 13 and 14 present comparable information for the high flow regimes. One set of oxygen profiles was produced in response to upstream BOD_5 loadings alone; a second set

TABLE 4

RATIOS USED TO ADJUST BOD_5 RATING CURVE AT ROSSER
FOR FUTURE LOADING CONDITIONS

PERIOD	BOD_5 RATIO*
Present	1.0
1979	0.40
Long Term	0.20

*Ratio used to project curve in Figure 5b
to future conditions.

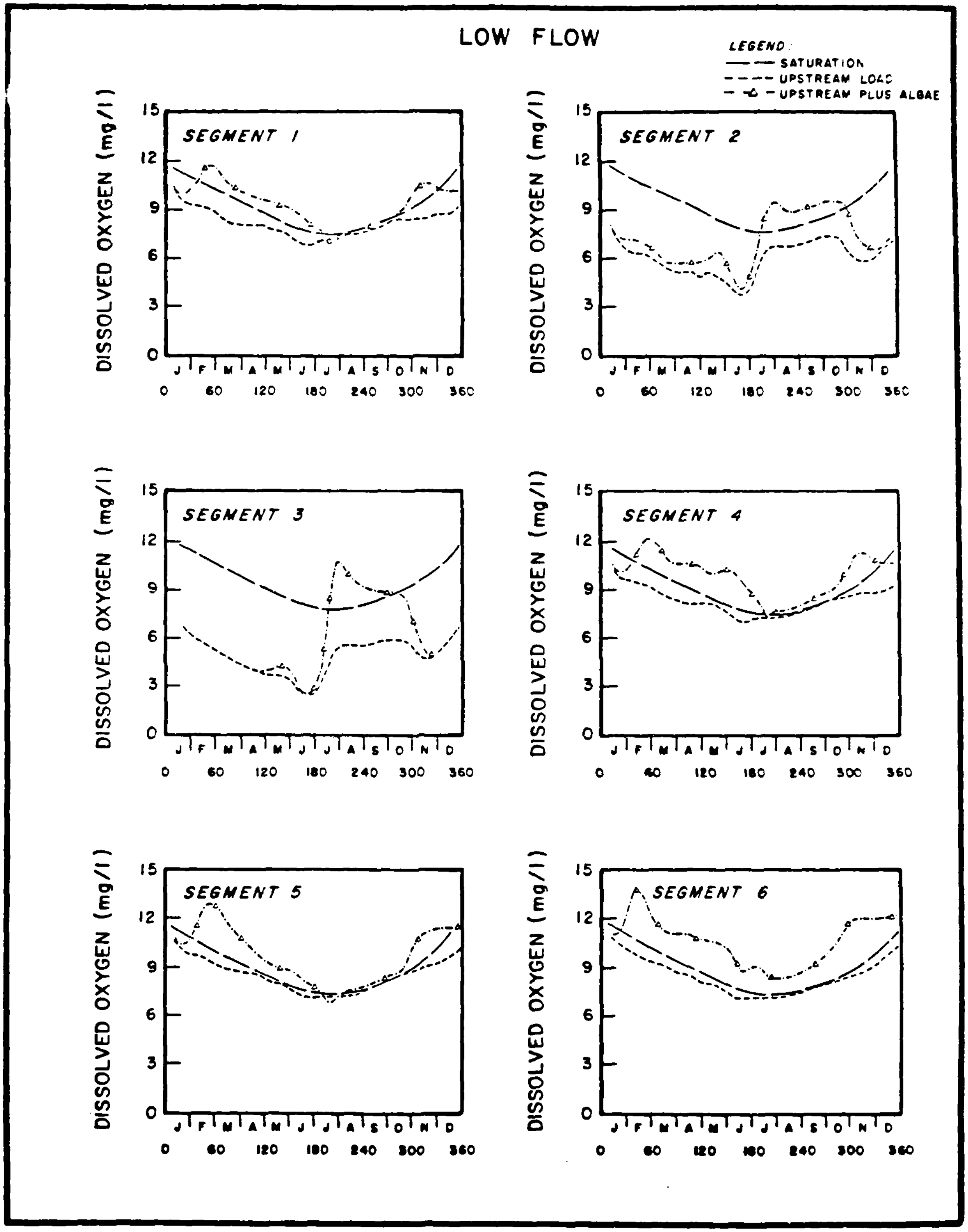


FIGURE 9
DISSOLVED OXYGEN CONCENTRATION PROJECTIONS
LOW FLOW HYDROLOGY, PRESENT LOADINGS

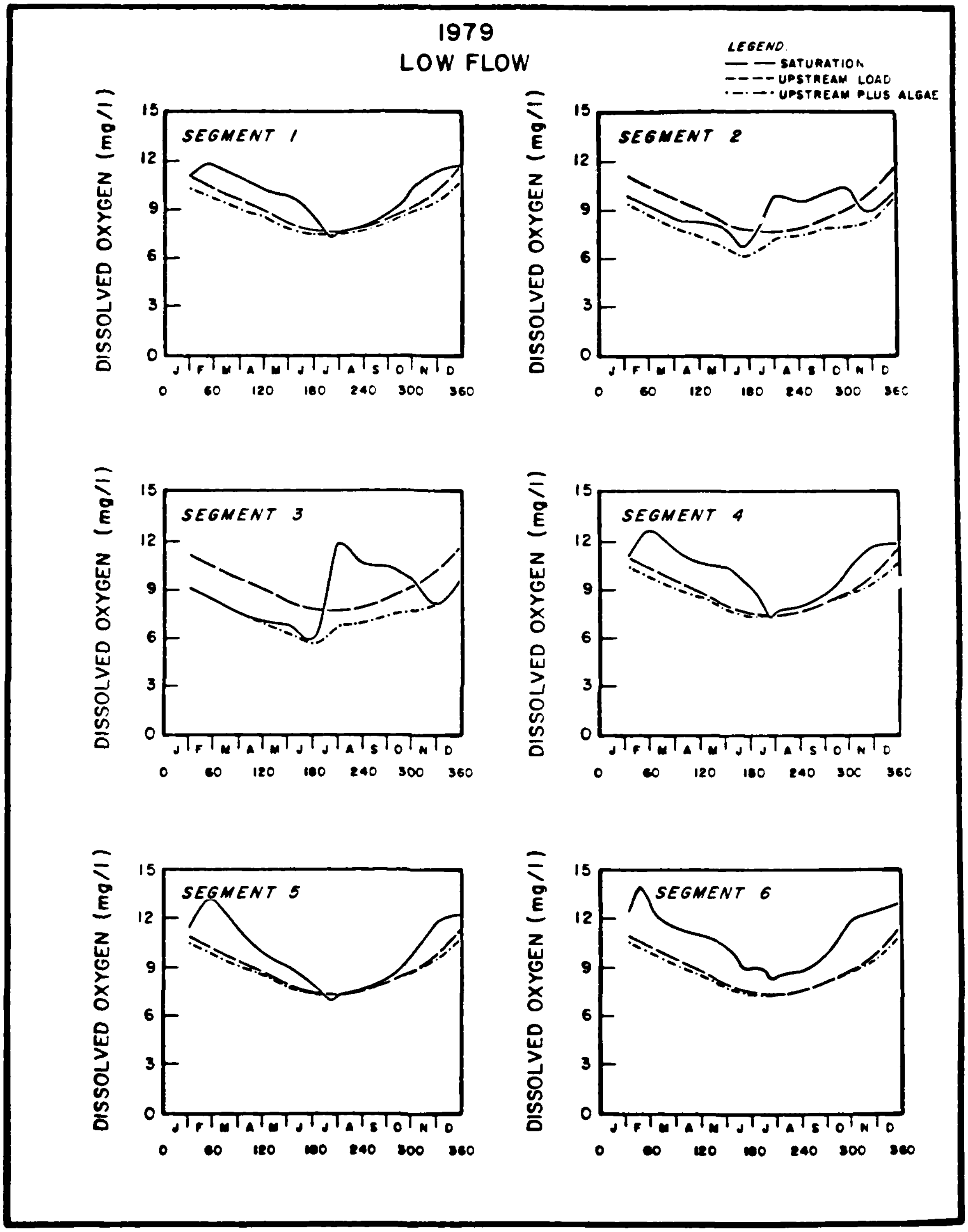


FIGURE 10
DISSOLVED OXYGEN CONCENTRATION PROJECTIONS
LOW FLOW HYDROLOGY, 1979 LOADINGS

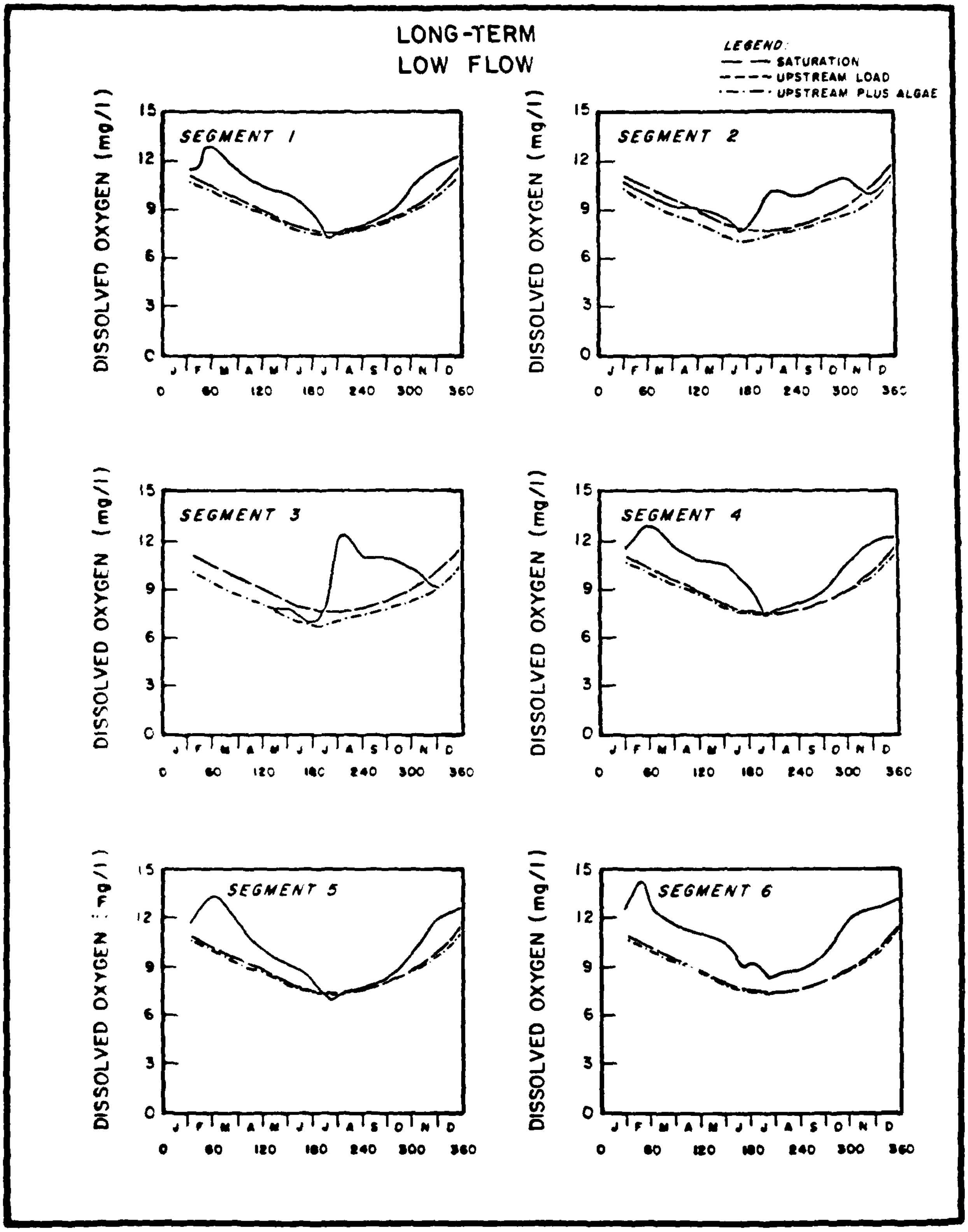


FIGURE 11
DISSOLVED OXYGEN CONCENTRATION PROJECTIONS
LOW FLOW HYDROLOGY, LONG-TERM LOADINGS

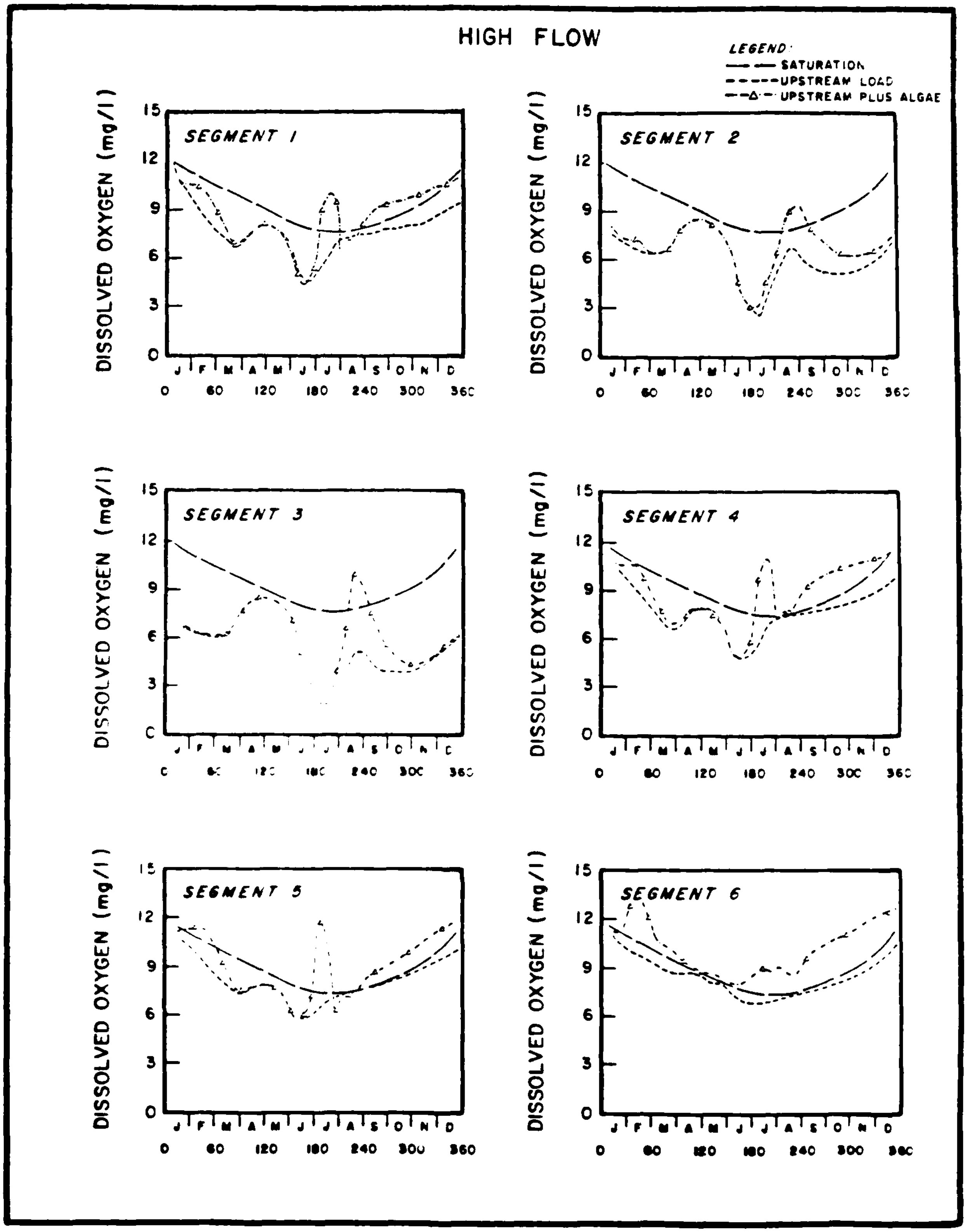


FIGURE 12
DISSOLVED OXYGEN CONCENTRATION PROJECTIONS
HIGH FLOW HYDROLOGY, PRESENT LOADINGS

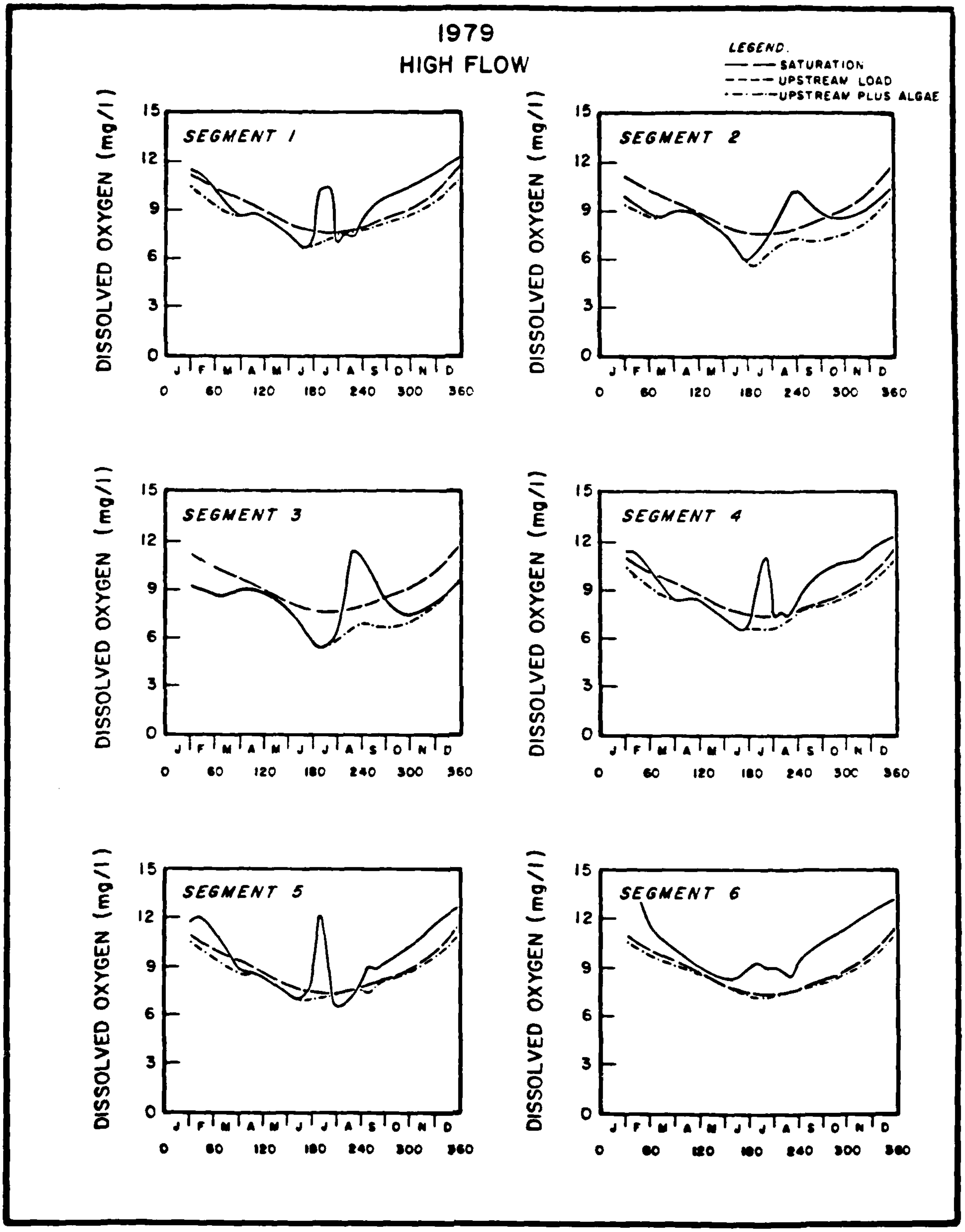


FIGURE 13

DISSOLVED OXYGEN CONCENTRATION PROJECTIONS HIGH FLOW HYDROLOGY, 1979 LOADINGS

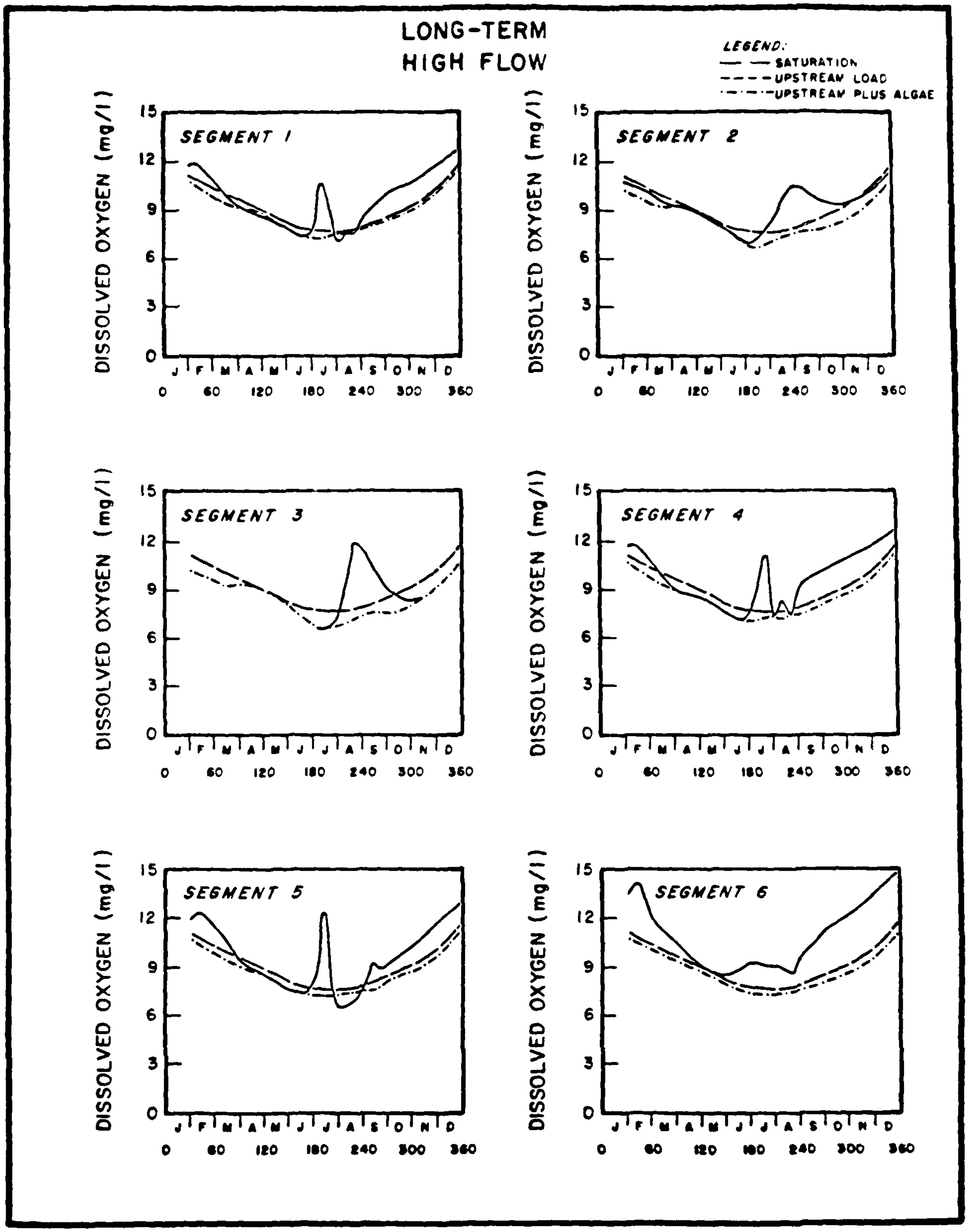


FIGURE 14
DISSOLVED OXYGEN CONCENTRATION PROJECTIONS
HIGH FLOW HYDROLOGY, LONG-TERM LOADINGS

of profiles indicates the combined impact of the upstream BOD_5 loadings plus the oxygen produced and used by phytoplankton growth and death. The calculations are performed assuming vertical uniformity in temperature and in BOD_5, phytoplankton and dissolved oxygen concentrations. Stratification of the channel region of the lake is possible under low flows, however. If strong vertical density gradients develop, bottom dissolved oxygen levels may be gradually reduced, in time, so that low dissolved oxygen concentrations could be present in early fall or late summer periods. This phenomenon has been observed in Lake Livingston.

The dissolved oxygen model as currently constructed does not include a component of oxygen demand from bottom deposits or from surface runoff other than the Trinity River. A reduction in the calculated dissolved oxygen level of approximately 1.0 to 1.5 mg/l could be associated with benthal deposits and other sources of oxygen demand.

Examination of Figures 9 through 14 indicates that, in general, dissolved oxygen levels will be high in the major portion of the proposed impoundment represented by Segments 5 and 6. These sections of the impoundment are shallow and vertical stratification should not cause dissolved oxygen problems. The sections of the proposed Tennessee Colony Lake which are channelized (Segments 1, 2 and 3) are projected to have periods when average dissolved oxygen levels drop to 3 mg/l under present loadings, assuming complete oxidation of incoming phytoplankton. Considering 1979 loading conditions or the situation with no significant oxidation of incoming plankton, average dissolved oxygen levels would reach lows of 5 mg/l. Sustained average high dissolved oxygen levels above 12 mg/l can be anticipated during the mid to late summer. There could be significant diurnal variations in dissolved

oxygen during these periods. The calculated dissolved oxygen profiles for the channel sections of the proposed impoundment indicate, for existing loads as shown in Figures 9 through 14, that spatial gradients will exist. Lower dissolved oxygen levels will be associated with the upstream reaches. Higher concentrations are calculated near the dam. This situation will tend to be offset, to some extent, by the increased depth associated with the channel area near the dam and the associated potential for vertical stratification. Vertical stratification in the channel areas will tend to result in low bottom dissolved oxygen levels.

The information presented in Figures 9 through 14 was developed without consideration of the oxygen demand associated with nitrification of ammonia nitrogen in the proposed impoundment. Under existing waste input levels, substantial concentrations of NH_3-N reach the site of the proposed lake. The possibility for nitrification of this ammonia exists, and if it occurs at significant rates a substantial additional reduction in dissolved oxygen can be anticipated.

There is no firm basis for predicting if nitrification will occur or the rate at which it will proceed. Nitrification is observed in lakes and streams under some conditions. If nitrification does occur at high rates, it is estimated the dissolved oxygen levels will be between one to two mg/l in the channelized portions of the lake. These lower dissolved oxygen levels will extend to the region of the dam. Nitrification generally ceases below DO concentrations of 1.0 to 1.5 mg/l. The lowering of dissolved oxygen concentrations due to nitrification could be associated with present and 1979 levels of waste

discharge. The long-term treatment goals indicated in Table 4 include nitrification at the treatment plants. Under this loading pattern, nitrification would probably not be a significant factor in the proposed Tennessee Colony Lake. The impact of nitrification on the non-channelized portions of the impoundment are anticipated to be minimal.

In the context of the assumptions and imperfectly understood phenomena discussed previously, the dissolved oxygen situation can be summarized in the following manner. Under 1979 waste input levels, assuming no significant nitrification within the proposed impoundment, calculated dissolved oxygen levels are generally in excess of 5 mg/l. Periodic or local values of dissolved oxygen below this level can be anticipated as a result of bottom oxygen demand, vertical stratification and following short-term algal blooms. If nitrification proceeds at high rates in the impoundment and not in the upstream sections of the Trinity River, summer dissolved oxygen levels in the channelized portions of the lake could drop to one to two mg/l.

CHAPTER IV
TRINITY RIVER WATER QUALITY

CHAPTER IV

TRINITY RIVER WATER QUALITY

A. Purpose.

A second major concern of the Phase II study is the impact of the proposed Tennessee Colony Lake on the water quality of the Trinity River. To address this concern, mathematical models were constructed to evaluate the water quality of the headwaters of Tennessee Colony Lake and to evaluate the water quality impacts in the river downstream of the dam as a result of releases from the proposed lake. The evaluation of the dissolved oxygen profiles in the river reaches which will be affected by the backwater from Tennessee Colony Lake is a major concern in this chapter. Another modeling study included in this chapter is the evaluation of the dissolved oxygen profiles below the Tennessee Colony Dam after releases of waters of various quality levels.

B. Milepoint Designations.

Several sets of river miles of the Trinity River have been cited in previous studies by the U.S. Corps of Engineers and the Trinity River Authority of Texas (TRA). Table 5 shows a comparison of river miles at selected locations according to the TRA system and the U.S. Corps of Engineers' system. Since the TRA has conducted previous water quality modeling studies of the Trinity River,[14] the TRA milepoint designations are referenced in this chapter. It is difficult to maintain a consistent set of milepoint designations since the length of the river has changed over the years as the result of oxbows being cut off and man-made changes in channel configuration. Furthermore, milepoints may be different in the future as a result of proposed channel modifications.

C. Previous Modeling Studies.

Mathematical models capable of representing dissolved oxygen conditions in the Trinity River upstream of Lake Livingston were developed in 1974 for the Trinity River Authority[14]. The project report evaluated the dissolved oxygen conditions in the Trinity River for the 300 miles from Fort Worth (Riverside) to below Crockett and presented a waste load allocation analysis. The study emphasizes the evaluation of dissolved oxygen profiles between Fort Worth and the East Fork. The report also recommended a continuing program to update water quality data and refine the model calculations.

D. Model Calibration for 1974 Conditions.

During the period of July 11-22, 1974, flow in the Trinity River reached a base flow of 45 cfs above the Riverside reach. During this time, the Trinity River Authority conducted intensive sampling surveys to determine the water quality characteristics of the river, which were not included in the initial calibration. The results of these sampling efforts provided a comprehensive picture of the characteristics of the Trinity River during low flow conditions and are summarized in the previous TRA report[14]. These data were used during this Phase II effort to extend the calibration of the Trinity River model into the portion of the river which would be affected by the proposed Tennessee Colony Lake. The model geometry, loadings, and reaction rates which were used are presented in Tables 6 through 8. Comparison of model results and measured dissolved oxygen concentrations are shown in Figure 15. The model results provide a good fit of the general trend of the data and can be considered an adequate representation of the water quality conditions in the river during low flow.

TABLE 5

COMPARISON OF TRA AND U.S. CORPS OF ENGINEERS MILEPOINTS

LOCATION	TRA*	U.S. CORPS OF ENGINEERS**
Big Fossil Creek	515.3	542.7
Village Creek	506.8	533.8
Elm Fork	479.7	505.5
East Fork	435.3	459.8
Trinity River entering Seg. 3 of Interim Tennessee Colony Lake (Elevation 240 ft)	362.8	-
Richland Creek	351.3	372.4
Seg. 3 to Seg. 2 of the Tennessee Colony Lake	334.9	-
Tehuacana Creek	328.1	347.2
Tennessee Colony Dam	323.5	341.7
Catfish Creek	320.7	339.6
Upper Keechi Creek	255.3	272.8
Lower Keechi Creek	226.1	240.5

*TRA River Miles are used in this report because previous modeling works were based on TRA River Miles.(14)

**Reference 2

TABLE 6

TRINITY RIVER MODEL GEOMETRY FOR JULY 11-12, 1974, CONDITIONS

	NO.	MILE-POINT	LENGTH (mi)	FLOW (cfs)	AREA (ft^2)	VELOCITY (ft/sec)	DEPTH (ft)	WIDTH (ft)	TRAVEL TIME (days)	ACCUM. TR. TIME (days)
Riverside	1	520	6	81	223.8	0.36	3.52	63.5	1.01	1.01
Handley Drive	2	514	5	81	223.8	0.36	3.52	63.5	0.84	1.85
Precinct Road	3	509	3	81	168.9	0.48	2.71	62.4	0.38	2.23
Village Creek	4	506	5	133	202.4	0.66	3.19	63.5	0.47	2.70
Hwy 157/Euless	5	501	6	133	256.8	0.52	3.73	68.9	0.71	3.41
Hwy 360	6	495	5	133	256.7	0.52	3.76	68.2	0.59	4.00
Arlington	7	490	7	133	237.8	0.56	3.79	62.8	0.76	4.76
TRA	8	483	3	185	280.8	0.66	4.04	69.5	0.28	5.04
Elm Fork	9	480	10	185	271.4	0.68	3.65	74.3	0.90	5.94
Dallas	10	470	15	355	502.6	0.71	6.05	83.1	1.30	7.24
South Side	11	455	9	361	505.6	0.71	6.08	83.2	0.77	8.01
Ten Mile Creek	12	446	11	367	455.8	0.81	5.29	86.2	0.84	8.85
East Fork	13	435	8	400	470.3	0.85	5.02	93.7	0.57	9.42
Rosser	14	427	19	400	615.9	0.65	4.82	127.7	1.79	11.2[illegible]
FM 85	15	408	20	400	445.4	0.90	4.53	98.2	1.36	12.57
Corsicana	16	388	17	400	449.8	0.89	4.80	93.8	1.17	13.74
Trinidad	17	371	7	400	567.0	0.71	4.93	114.9	0.61	14.35
Cedar Creek	18	364	13	401	570.2	0.70	5.04	113.2	1.13	15.48
Richland Creek	19	351	30	484	618.5	0.78	5.21	118.6	2.34	17.82
Catfish Creek	20	321	26	508	638.4	0.80	5.28	120.9	2.00	19.82
Oakwood	21	295	20	508	835.5	0.61	5.26	158.8	2.01	21.83
Glaze Lake	22	275	27	508	835.5	0.61	5.26	158.8	2.71	24.54
Crockett	23	248	20	508	866.5	0.59	5.26	164.6	2.09	26.63

TABLE 7

LOADINGS TO THE TRINITY RIVER DURING JULY 11-22, 1974

REACH	NO.	MILE-POINT	LENGTH (mi)	INFLOW (cfs)	D.O. (mg/l)	BOD_5 (mg/l)	NH_3-N (mg/l)	TOTAL FLOW (cfs)
Riverside	1	520	6	36	4.4	34	7.0	81
Handley Drive	2	514	5	0	0	0	0	81
Precinct Road	3	509	3	0	0	0	0	81
Village Creek	4	506	5	52	6.6	12	4.0	133
Hwy 157/Euless	5	501	6	0	0	0	0	133
Hwy 360	6	495	5	0	0	0	0	133
Arlington	7	490	7	0	0	0	0	133
TRA	8	483	3	52	6.6	22	12.0	185
Elm Fork	9	480	10	0	0	0	0	185
Dallas	10	470	15	170	6.6	49	11.0	355
South Side	11	455	9	6	2.3	41	23.0	361
Ten Mile Creek	12	446	11	6	2.3	4	2.0	367
East Fork	13	435	8	33	2.7	35	6.6	400
Rosser	14	427	19	0	0	0	0	400
F M 85	15	408	20	0	0	0	0	400
Corsicana	16	388	17	0	0	0	0	400
Trinidad	17	371	7	0	0	0	0	400
Cedar Creek	18	364	13	1	6.0	0	0	416
Richland Creek	19	351	30	83	6.0	4	0.2	499
Catfish Creek	20	321	26	24	5.0	4	0.2	523
Oakwood	21	295	20	0	0	0	0	523
Glaze Lake	22	275	27	0	0	0	0	523
Crockett	23	248	20	0	0	0	0	523

TABLE 8

TRINITY RIVER REACTION RATES (BASE e @ 20°C) FOR JULY 11-22, 1974, CONDITIONS

Reach	No.	Mile-Point	K_a (1/day)	K_r (1/day)	K_d (1/day)	K_n (1/day)	Benthal Demand (gm/m^2-day)	Temp. (°C)
Riverside	1	520	1.18	0.30	0.20	0.00	1.5	30
Handley Drive	2	514	1.18	0.30	0.20	0.00	1.5	30
Precinct Road	3	509	2.01	0.30	0.20	0.00	1.5	30
Village Creek	4	506	1.85	0.30	0.20	0.00	3.0	30
Hwy 157/Euless	5	501	1.30	0.30	0.20	0.00	3.0	30
Highway 360	6	495	1.28	0.30	0.20	0.00	3.0	30
Arlington	7	490	1.31	0.30	0.20	0.00	3.0	30
TRA	8	483	1.29	0.30	0.20	0.00	3.0	30
Elm Fork	9	480	1.53	0.30	0.20	0.00	3.0	30
Dallas	10	470	0.73	0.30	0.20	0.00	3.0	30
South Side	11	455	0.73	0.30	0.20	0.00	1.5	30
Ten Mile Creek	12	446	0.96	0.30	0.20	0.00	1.5	30
East Fork	13	435	1.06	0.30	0.20	0.05	1.5	30
Rosser	14	427	0.99	0.20	0.20	0.07	1.0	30
FM 85	15	408	1.27	0.20	0.20	0.15	1.0	30
Corsicana	16	388	1.16	0.20	0.20	0.20	1.0	30
Trinidad	17	371	0.99	0.20	0.20	0.20	1.0	30
Cedar Creek	18	364	0.96	0.20	0.20	0.20	1.0	30
Richland Creek	19	351	0.96	0.20	0.20	0.20	1.0	30
Catfish Creek	20	321	0.95	0.20	0.20	0.20	1.0	30
Oakwood	21	295	0.84	0.20	0.20	0.20	1.0	30
Glaze Lake	22	275	0.84	0.20	0.20	0.20	1.0	30
Crockett	23	248	0.82	0.20	0.20	0.20	1.0	30

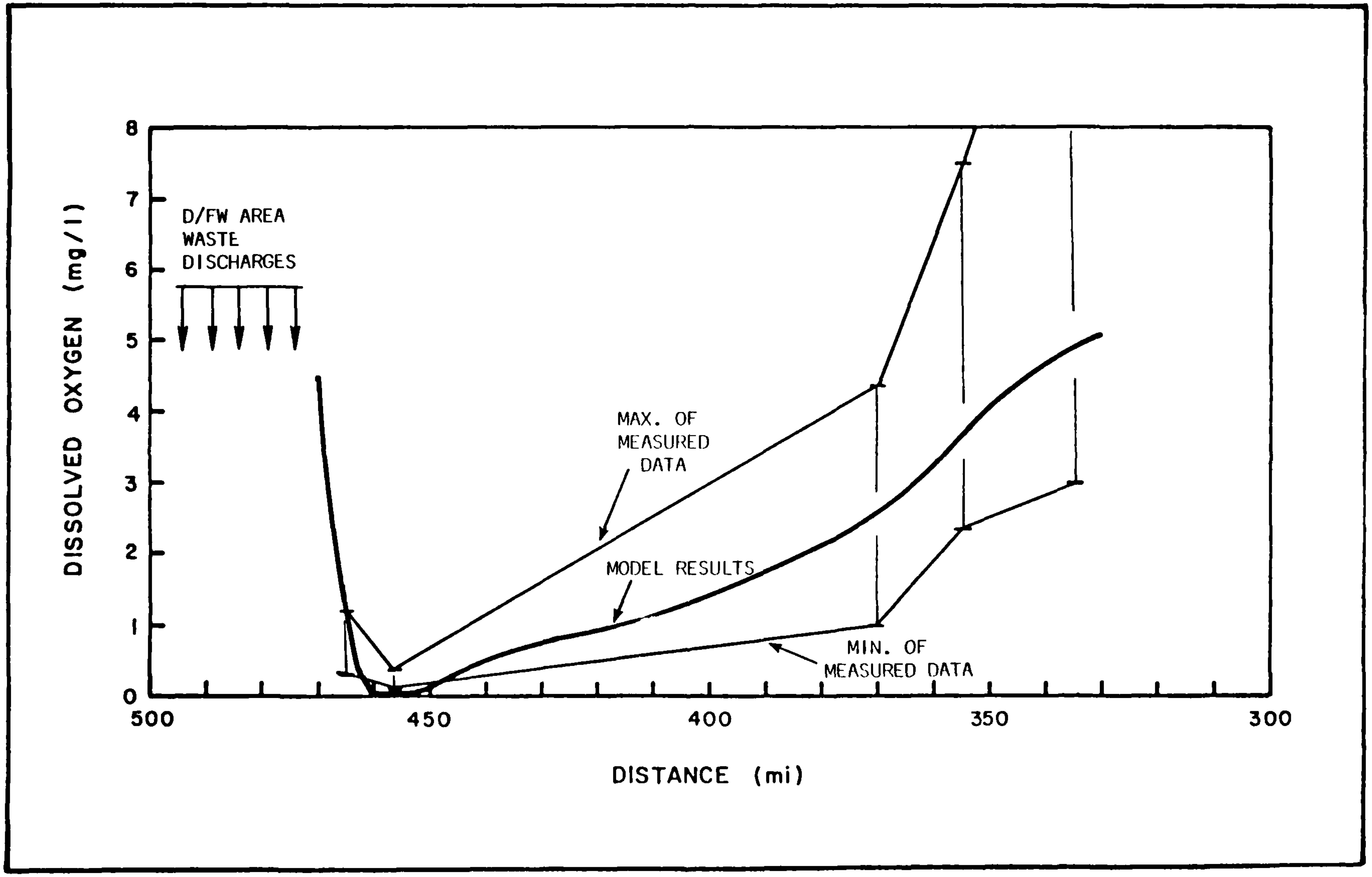


FIGURE 15
CALCULATED AND OBSERVED DISSOLVED OXYGEN LEVELS
IN THE UPPER TRINITY RIVER (JULY 11-22, 1974)

E. Modeling Analysis of the Headwaters of the Proposed Tennessee Colony Lake.

This section discusses the application of a portion of the recalibrated river model to the headwaters of the proposed Tennessee Colony Lake. The analysis performed dealt with the computed changes in low flow dissolved oxygen profiles resulting from the Trinity River entering the wider and deeper transition section of the lake. The impact of tributary flows and municipal wastewater treatment plant effluents entering in the Dallas/Fort Worth area, which create loads of BOD_5 and ammonia, was modeled. Four basic configurations were analyzed: present river geometry with and without instream nitrification of ammonia, and lake-modified geometry also with and without instream nitrification of ammonia. These four configurations were analyzed under several projected loading patterns.

A detailed discussion of the mathematical form of the model will not be presented in this report. The model which was previously developed for the TRA is adequately described in the previous report[14]. Instead, only the particulars of this application will be discussed below, including model segmentation and geometry with the interim pool of Tennessee Colony Lake, model kinetics, and the results of the dissolved oxygen analyses for projected future loadings.

1. Segmentation. The most useful form of the equation for the spatial distribution of dissolved oxygen deficit and other water quality variables in a river is derived assuming constant coefficients for a specific portion of a river. Thus, an initial step in river modeling involves division of the river into reaches of relatively constant characteristics. The water quality equation may then be applied separately to each segment of the system to calculate a spatial concentration profile within the respective segment.

At the junctio between segments, mass balances are performed to determine the initial condition of the succeeding segment in the system.

In summary, a new segment must be established for the following reasons:

- at the location of any significant flow discontinuity in the system; such additional flow may be in the form of a tributary or wastewater discharge
- on the basis of significant changes in physical characteristics such as cross-sectional area, depth, width, velocity, reaeration or temperature
- when any of the reaction rates or oxygen demands are known to vary significantly with distance

The proposed Tennessee Colony Lake headwaters start at river mile 362.8 when the conservation pool is maintained at an elevation of 240 feet. From this location down to river mile 334.9, the river characteristics led to a division of the headwater reach (Segment 3 of the lake model presented in Chapter III) into eight segments. Thus, a total of 26 segments is used in the modified Trinity River model for the evaluation of water quality in the headwaters of Tennessee Colony Lake.

2. Geometry. The velocity, depth, width, and cross-sectional area for a specific segment of a river can often be expressed as power functions of flow. The following equations are used to relate these parameters for each model segment:

Velocity:	$U = C_U Q^{N_U}$	(2a)
Depth:	$H = C_H Q^{N_H}$	(2b)
Width:	$W = C_W Q^{N_W}$	(2c)
Cross-sectional Area:	$A = C_A Q^{N_A}$	(2d)

in which C_U, C_H, C_W, and C_A are constants of proportionality and N_U, N_H, N_W, and N_A are exponential constants. By reason of continuity, these coefficients are related by the following expressions:

$$C_A = 1/C_U \tag{3a}$$

$$C_W = C_A/C_H \tag{3b}$$

$$N_A = 1 - N_U \tag{3c}$$

$$N_W = N_A - N_H \tag{3d}$$

Thus, a complete set of proportionality constants can be determined if C_A or C_U is known and C_W or C_H is known. Likewise, the exponential constants may be determined if N_A or N_U is known and N_W or N_H is known.

Information on time of travel and river geometry was obtained from the following sources:

- Above river mile 362.8, the river geometry developed by Hydroscience in the previous modeling effort was adopted

- Below river mile 362.8, the average depth and width of the river with the lake at an elevation of 240 feet have been estimated by using available U.S. Army Corps of Engineers' cross-sectional data

The present exponential relationships for geometry of the various model segments are shown in Table 9. Revision of these relationships can be made as additional data become available.

3. Kinetics. The reaeration rates (K_a), carbonaceous removal and deoxygenation rates (K_r and K_d), nitrogenous decay rates (K_n) and benthal uptake rates (S) are parameters related to sources and sinks of the dissolved oxygen in a river. These reactions are described below. All reaction rates are expressed to the base e.

a. Reaeration Rates. The reaeration coefficients were calculated using the O'Connor-Dobbins formulation:

$$K_a = \frac{(D_L U)^{1/2}}{H^{3/2}} \tag{4a}$$

where D_L is the oxygen diffusivity at 20°C and is equal to 0.000081 ft^2/hr; U is average stream velocity for the segment; and H is the average depth for the segment and is defined as the cross-sectional area divided by the channel width measured at the water surface. When velocity is expressed in feet per second and depth in feet, this becomes:

$$K_a = \frac{12.96\ U^{1/2}}{H^{3/2}} \tag{4b}$$

TABLE 9

TRINITY RIVER GEOMETRY RELATIONSHIPS

Reach	No.	Mile-Point	Velocity (fps) C_U	Velocity (fps) N_U	Area (ft^2) C_A	Area (ft^2) N_A	Depth (ft) C_H	Depth (ft) N_H	Width (ft) C_W	Width (ft) N_W
Riverside	1	502	0.0258	0.601	38.665	0.389	0.9103	0.308	42.471	0.090
Handley Drive	2	514	0.0258	0.601	38.665	0.389	0.9103	0.308	42.471	0.090
Precinct Road	3	509	0.0283	0.644	35.291	0.355	0.6872	0.312	51.353	0.042
Village Creek	4	506	0.0279	0.646	35.715	0.353	0.6996	0.310	51.047	0.043
Highway 157	5	501	0.0221	0.645	45.071	0.354	0.9430	0.281	47.792	0.073
Highway 360	6	495	0.0220	0.646	45.304	0.353	0.9660	0.278	46.894	0.075
Arlington	7	490	0.0241	0.643	41.448	0.356	0.9919	0.274	41.786	0.082
TRA	8	483	0.0389	0.542	25.701	0.457	0.8013	0.310	32.071	0.147
Elm Fork	9	480	0.0386	0.550	25.857	0.449	0.5521	0.362	46.832	0.086
Dallas	10	470	0.0160	0.645	62.317	0.354	1.0210	0.303	61.030	0.050
South Side	11	455	0.0160	0.645	62.317	0.354	1.0220	0.303	61.030	0.050
Ten Mile Creek	12	446	0.0955	0.361	10.465	0.635	0.4029	0.436	25.975	0.201
East Fork	13	435	0.0506	0.471	19.751	0.528	0.4708	0.395	41.944	0.133
Rosser	14	427	0.0186	0.593	53.670	0.406	0.5890	0.351	91.119	0.054
FM 85	15	408	0.0679	0.431	14.713	0.568	0.3574	0.424	41.159	0.144
Corsicana	16	388	0.0529	0.471	18.892	0.528	0.4693	0.388	40.249	0.140
Trinidad	17	371	0.0271	0.544	36.888	0.455	0.5280	0.373	69.855	0.082
Cedar Creek	18	364	0.0428	0.467	23.319	0.532	0.3944	0.425	59.124	0.106
R.M. 362	19	362.8	0.000736	1.0	1358.9	0.	10.7	0.	127.	0.
Wildcat Creek	20	358	0.000540	1.0	1851.3	0.	12.1	0.	153.	0.
U.S. Hwy No.287	21	354	0.000435	1.0	2296.8	0.	13.2	0.	174.	0.
Richland Creek	22	351	0.000369	1.0	2707.2	0.	14.1	0.	192.	0.
R.M. 348	23	348	0.000309	1.0	3237.6	0.	15.2	0.	213.	0.
Mitchells Branch	24	344	0.000261	1.0	3820.5	0.	16.3	0.	235.	0.
Lindsey Slough	25	341	0.000228	1.0	4376.9	0.	17.3	0.	253.	0.
R.M. 338	26	338	0.000202	1.0	4959.3	0.	18.3	0.	271.	0.

The unit of K_a in both formulations is day^{-1} to the base e at 20°C.

Where the Trinity River enters the headwaters of the Tennessee Colony Lake, the cross-sectional area and depth increase significantly. This would result in very low velocity in these segments. The reaeration rates (K_a) for these segments are calculated by using the empirical formula[15]:

$$K_a = \frac{2}{H} \tag{4c}$$

where H is the average segment depth in feet. The values of K_a in the headwater reaches of the lake range from 0.12 to 0.17/day.

b. Carbonaceous Demands. For river water quality surveys, carbonaceous oxygen demand is often expressed in terms of BOD_5. The river BOD removal rate (K_r) can be estimated by using the BOD_5 data collected at the various locations of the river. Based upon the previous modeling studies, a deoxygenation rate (K_r) of 0.2/day was chosen for the model. Because significant settling occurs at locations below treatment plant discharges, a slightly higher total BOD_5 removal rate (K_r) of 0.3/day has been assumed in the model in the regions downstream of treatment plants.

c. Nitrogenous Demands. The action of the nitrifying bacteria can also consume dissolved oxygen in a river through the oxidation of nitrogenous compounds. According to the ammonia nitrogen profiles for the Trinity River, the decay rate (K_n) of 0.0 to 0.2/day was selected for the modeling of that parameter for various portions of the river. Generally, dissolved oxygen concentrations must be above 1.5 mg/l for nitrification to occur. This assumption affected the choice of nitrification rates for this portion of the river.

d. Benthic Demand. Based upon the previous water quality studies of the Trinity, benthic demands were felt to be significant in certain segments, especially those immediately downstream from sewage treatment plants. Therefore, deoxygenation due to benthic demand was incorporated into the model. The values used in the model are based upon generally accepted values of oxygen uptake rates for municipal sewage sludge in a river. Values in the range of 1.0 to 4.0 gm/m^2-day are considered representative. With these factors in mind, a value of 1.0 to 1.5 gm/m^2-day was chosen for those sections with the major wastewater treatment plant (WWTP) discharges and a value of 1.0 gm/m^2-day was selected for the sections further downstream of these major discharges. These values include adjustments for projected improvements in waste treatment plants discharging to the Trinity.

e. Temperature Correction Factors. In the previous discussion, the decay rates, reaeration rates and benthal uptake rates were given to the base e at 20°C. In the various model runs, appropriate temperature correction factors are applied according to the following formulas:

$$\text{Carbonaceous Decay:} \quad (K_d)_T = (K_d)_{20} \; (1.047)^{T-20} \qquad (5a)$$

$$\text{Nitrogenous Decay:} \quad (K_n)_T = (K_n)_{20} \; (1.047)^{T-20} \qquad (5b)$$

$$\text{Reaeration:} \quad (K_a)_T = (K_a)_{20} \; (1.024)^{T-20} \qquad (5c)$$

$$\text{Benthal Uptake:} \quad (S)_T + (S)_{20} \; (1.08)^{T-20} \qquad (5d)$$

A summer water temperature of 30°C was used in the simulations.

4. Point Source Loads. Projections for point source discharge volumes entering the Trinity upstream of the lake

were developed for the years 1980 and 1990. These projected wastewater treatment plant (WWTP) discharges and tributary flows are shown in Table 10.

By the year 1980, it is estimated that 10 mg/l BOD_5, 15 mg/l TSS and 10 mg/l NH_3-N treatment levels will be achieved at the major dischargers to the Trinity River. This level of treatment was modeled for projected wastewater volumes under 1980 and 1990 conditions. In order to investigate some possible effects of even higher treatment levels, the treatment combination of 5 mg/l BOD_5, 5 mg/l TSS AND 3 mg/l NH_3-N was also modeled for projected wastewater volumes under 1990 conditions. Table 11 summarizes the effluent concentration and instream reaction rates for these three conditions. Several other future treatment and reaction rate combinations are possible; the conditions reflected in Table 11 were chosen simply for the sake of example.

5. Dissolved Oxygen Analysis. Multiple computer runs were conducted to obtain results for the dissolved oxygen profiles under the various loading conditions. Table 12 provides, as an example, the model geometry under 1980 discharge volumes and low flow conditions.

Nitrification in a river is an uncertain reaction which may or may not occur under future conditions in the Trinity River. As mentioned previously, one factor which limits nitrification is the dissolved oxygen concentration. Furthermore, other phenomena such as algal uptake or stripping may reduce the ammonia concentration in the river. Thus, the nitrogen cycle in a river such as the Trinity is difficult to evaluate. For this reason, computer model results were obtained for projected loading conditions with and without nitrification of ammonia occurring in the river. This approach hopefully brackets the range of possibilities to be expected in this portion of the river.

TABLE 10

PROJECTED TRIBUTARY FLOWS AND MUNICIPAL WASTEWATER TREATMENT PLANT DISCHARGES TO THE UPPER TRINITY RIVER

	Year 1980 (cfs)	Year 1990 (cfs)
Upstream (above Fort Worth)	50	50
Village Creek WWTP	131.5	162.4
TRA Central WWTP	116.0	201.0
Elm Fork	22.0	33.1
Dallas WWTP (2 plants)	278.0	324.9
TRA Tenmile Creek WWTP	17.0	20.9
East Fork	68.4	125.6
Richland Creek	83.0	83.0

TABLE 11

UPPER TRINITY RIVER MODEL RUNS FOR VARIOUS EFFLUENT SETS

YEAR	WASTEWATER TREATMENT PLANT EFFLUENT SETS (BOD_5/TSS/NH_3-N as mg/l)	VILLAGE CREEK TO ROSSER*				BELOW ROSSER*			
		K_r (1/day)	K_d (1/day)	K_n (1/day)	S (g/m^2 day)	K_r (1/day)	K_d (1/day)	K_n (1/day)	S (g/m^2 day)
1980	10/15/10	0.25	0.20	0-0.2	1.5	0.2	0.2	0-0.2	1.0
1990	10/15/10	0.25	0.20	0-0.2	1.5	0.2	0.2	0-0.2	1.0
1990	5/5/3	0.20	0.20	0-0.2	1.0	0.2	0.2	0-0.2	1.0

*base e @ 20°C

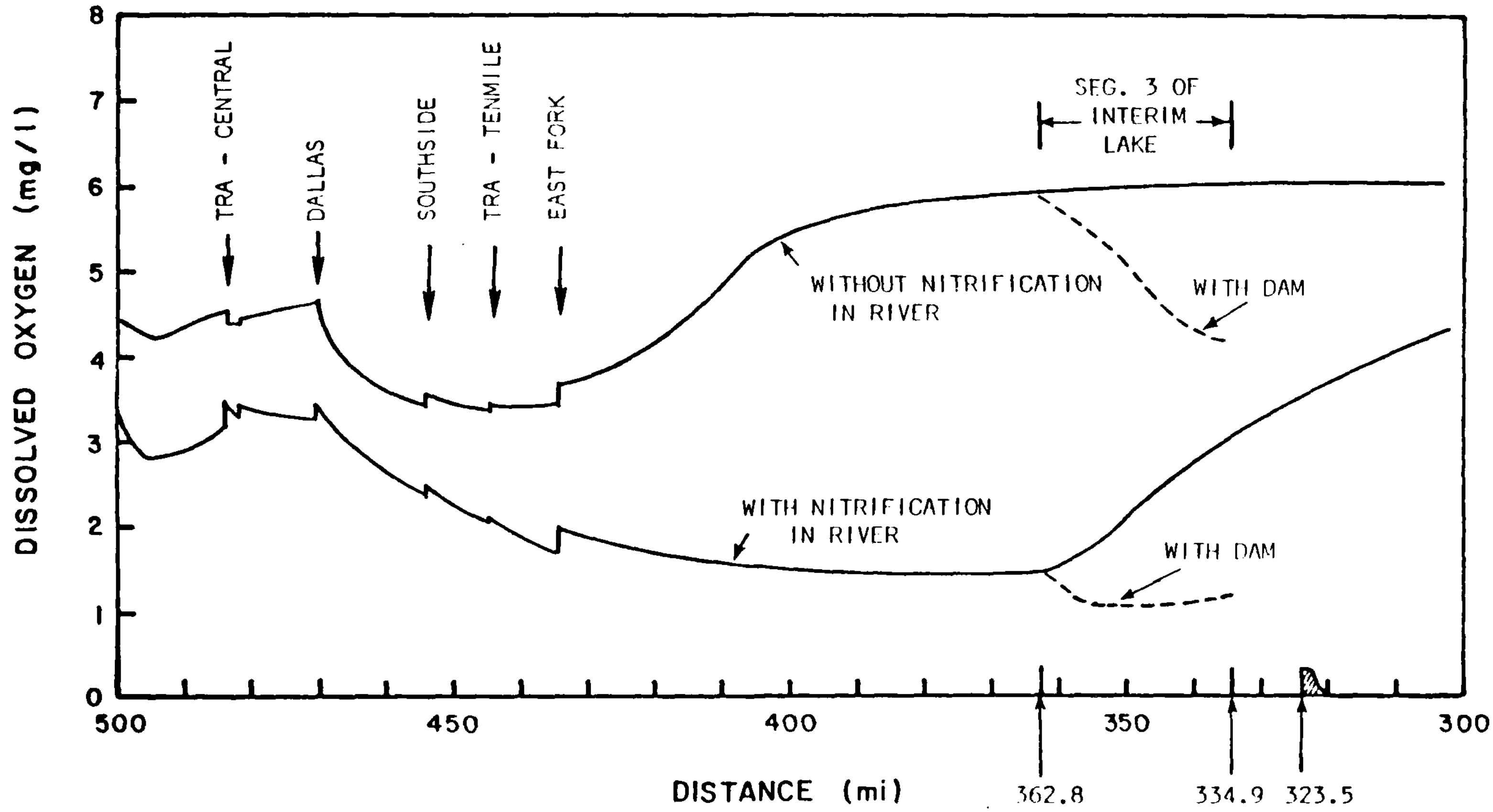
TABLE 12

UPPER TRINITY RIVER MODEL GEOMETRY (WITH TENNESSEE COLONY LAKE)

REACH	NO.	MILE-POINT	LENGTH (mi)	FLOW (cfs)	AREA (ft^2)	VELOCITY (ft/sec)	DEPTH (ft)	WIDTH (ft)	TRAVEL TIME (days)	ACCUM. TR. TIME (days)
Riverside	1	520	6	50.0	184.6	0.27	3.04	60.8	1.35	1.35
Handley Drive	2	514	5	50.0	184.6	0.27	3.04	60.8	1.13	2.48
Precinct Road	3	509	3	50.0	142.2	0.35	2.33	61.1	0.52	3.00
Village Creek	4	506	5	181.5	226.0	0.80	3.51	64.4	0.38	3.38
Hwy 157/Euless	5	501	6	181.5	286.8	0.63	4.07	70.5	0.58	3.96
Hwy 360	6	495	5	181.5	286.8	0.63	4.10	69.9	0.48	4.44
Arlington	7	490	7	181.5	265.7	0.68	4.12	64.4	0.63	5.07
TRA Central	8	483	3	297.5	349.1	0.85	4.68	74.5	0.22	5.29
Elm Fork	9	480	10	319.5	347.1	0.92	4.45	78.0	0.66	5.95
Dallas	10	470	15	519.5	575.3	0.90	6.67	84.7	1.02	6.97
Southside	11	455	9	597.5	604.6	0.99	7.08	85.4	0.56	7.53
Tenmile Creek	12	446	11	614.5	633.7	0.97	6.62	95.7	0.69	8.22
East Fork	13	435	8	682.9	624.1	1.09	6.20	100.7	0.45	8.67
Rosser	14	427	19	682.9	765.7	0.89	5.82	131.6	1.30	9.97
FM 85	15	408	20	682.9	603.8	1.13	5.69	106.2	1.08	11.05
Corsicana	16	388	17	682.9	596.9	1.14	5.90	101.1	0.91	11.96
Trinidad	17	371	7	682.9	723.6	0.94	6.02	120.1	0.45	12.41
Cedar Creek	18	364	1.2	682.9	757.3	0.90	6.32	119.9	0.08	12.49
RM 363	19	362.8	4.8	682.9	1358.7	0.50	10.70	127.0	0.58	13.07
Wildcat Creek	20	358	4	682.9	1851.9	0.37	12.10	153.1	0.66	13.73
Hwy 287	21	354	3	682.9	2298.9	0.30	13.20	174.2	0.62	14.35
Kirkland Creek	22	351	3	765.9	2710.0	0.28	14.10	192.2	0.65	15.00
RM 348	23	348	4	765.9	3268.0	0.23	15.20	215.0	1.04	16.04
Mitchells Branch	24	344	3	765.9	3831.4	0.20	16.30	235.1	0.92	16.96
Lindsey Slough	25	341	3	765.9	4386.0	0.17	17.30	253.5	1.05	18.01
RM 338	26	338	3.1	765.9	4950.5	0.15	18.30	270.5	1.22	19.23

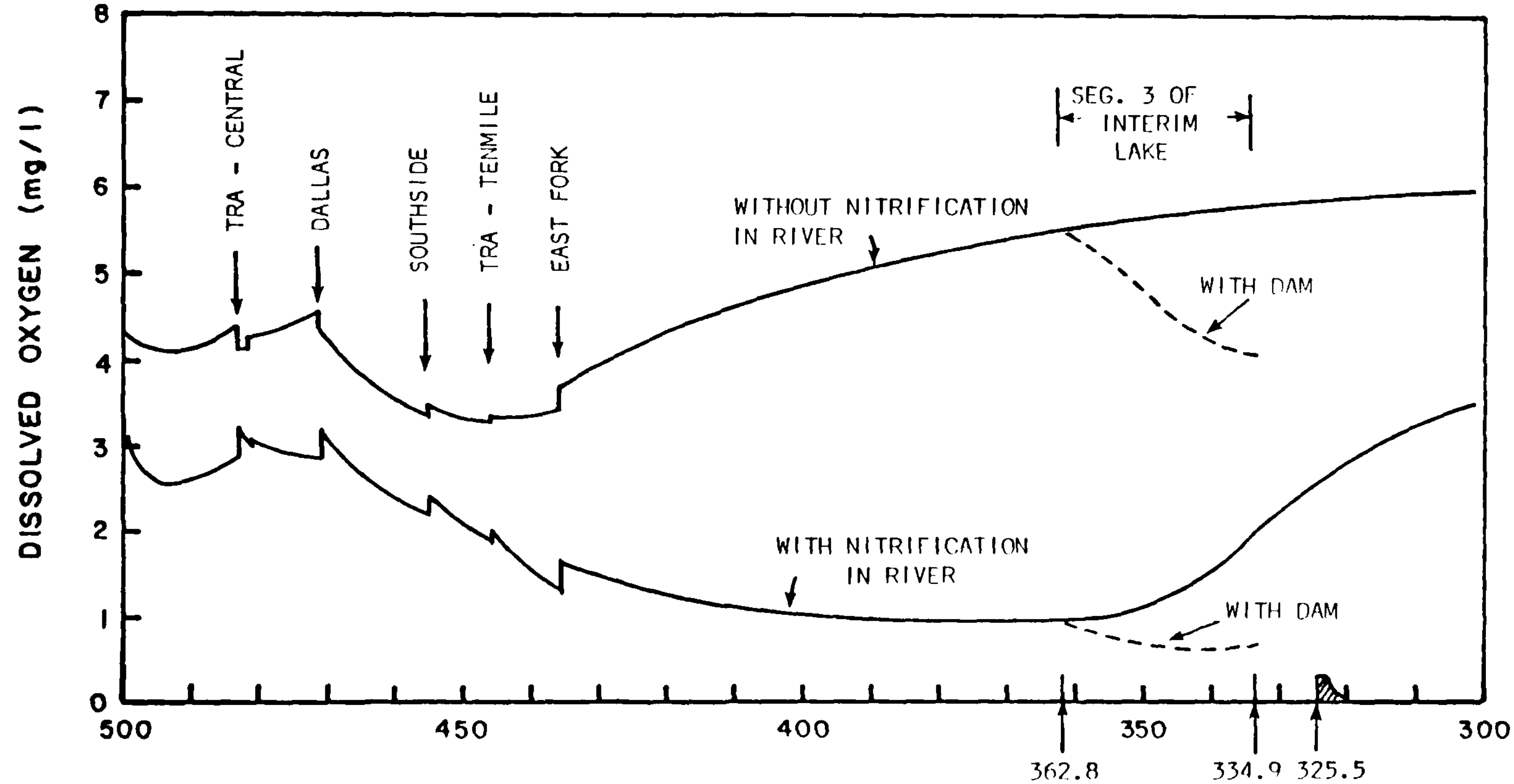
The DO profiles in the river were projected based upon a stream flow which consisted of upstream flow from the headwaters above Dallas/Fort Worth and the waste treatment effluent generated in Dallas/Fort Worth. An upstream flow of 50 cfs was used as the low flow case. The projected profiles using a background of 100 cfs and 342 cfs showed a less severe DO depression than under the 50 cfs condition. The results of the analyses using 50 cfs are shown in Figures 16 through 18. Figure 16 represents 1980 conditions with 10/15/10 treatment levels at all major treatment plants. Figure 17 represents 1990 conditions with 10/15/10 treatment levels at all major treatment plants. The differences in the various dissolved oxygen profiles between these two years is minimal. Figure 18 represents 1990 conditions with 5/5/3 treatment levels at all major plants.

For all three figures, the same general conclusion can be made: the backing up of the water in the headwater region of Tennessee Colony Lake will apparently cause the dissolved oxygen to drop by 1.5 to 3.0 mg/l. A portion of this drop would be caused by the pollutants remaining in the river water in this region and a portion of this drop would be caused by the benthal demand. Under present conditions, in the area where the future headwaters of Tennessee Colony Lake will be located, the Trinity River is in a state of recovery from the dissolved oxygen depression caused by the pollutant loads in the Dallas/Fort Worth area. Location of the lake headwaters in this region will slow down the velocity, reduce the reaeration, and cause a secondary depression of DO, as shown in the figures. For the assumed conditions without nitrification, the low dissolved oxygen concentration is projected to be between



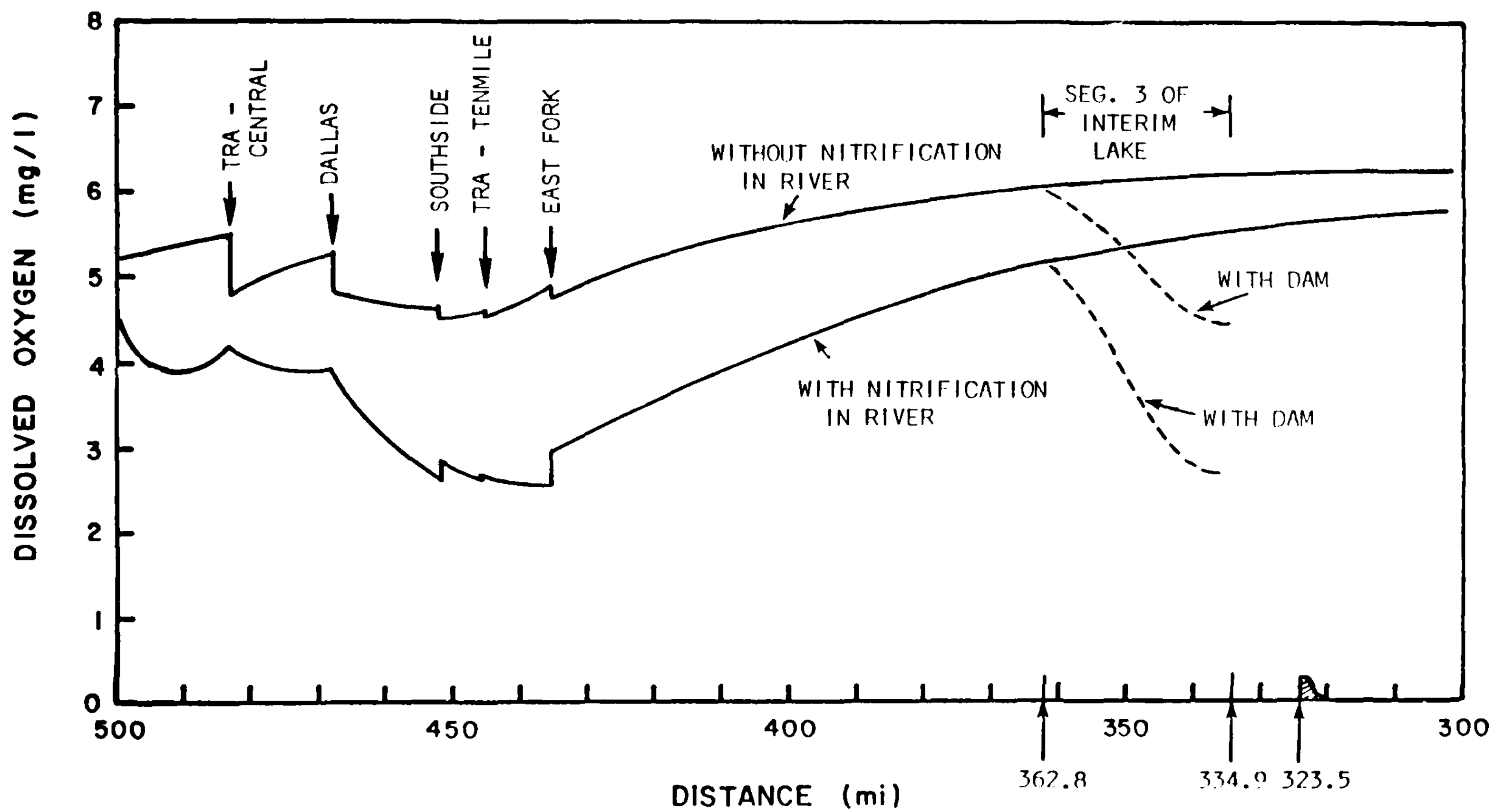
Note: 1. DISTANCES ARE 'TRA' RIVER MILES.
2. MAJOR POINT SOURCE DISCHARGES:
(BOD_5 = 10 mg/l, TSS = 15 mg/l, NH_3-N = 10 mg/l)

FIGURE 16
CALCULATED DISSOLVED OXYGEN PROFILES
IN THE UPPER TRINITY RIVER
1980, LOW FLOW CONDITIONS (10/15/10)



NOTES: 1. DISTANCES ARE 'TRA' RIVER MILES.
2. MAJOR POINT SOURCE DISCHARGES:
(BOD_5 = 10 mg/l, TSS = 15 mg/l, NH_3-N = 10 mg/l)

FIGURE 17
1990, LOW FLOW CONDITIONS (10/15/10)



NOTES: 1. DISTANCES ARE 'TRA' RIVER MILES.
2. MAJOR POINT SOURCE DISCHARGES:
(BOD_5 = 5 mg/l, TSS = 5 mg/l, NH_3-N = 3 mg/l)

FIGURE 18

1990, LOW FLOW CONDITIONS (5/5/3)

4 and 5 mg/l, depending upon the upstream loading levels. For the assumed conditions with nitrification, the low dissolved oxygen concentration is projected to be between 1 and 3 mg/l, depending upon the upstream loading levels.

These analyses are meant only to show the relative impact of the various conditions studied. Numerous other combinations of parameters could be possible. For example, the present analysis does not take algal activity directly into account. Algal activity would presumably cause wide diurnal swings in dissolved oxygen in this portion of the river and several of the dissolved oxygen profiles shown could be raised somewhat on the daily average as a net result of algal activity.

F. Modeling Analysis of the Trinity River Below the Tennessee Colony Lake Dam.

The second mathematical model was developed to evaluate the water quality in the Trinity River brought about by the releases from the proposed Tennessee Colony Lake. The analysis was primarily concerned with the direct effects of these releases on the dissolved oxygen profiles downstream of the Tennessee Colony Dam. A range of reasonable ultimate oxygen demand (UOD) and DO concentrations in the dam release water was used. In addition, two flow regimes were studied: a low flow of 680 cfs and a moderate flow of 3000 cfs. The predicted effects of these release waters of various quality may aid in the selection of the release structure design and operation.

As in the preceding analysis, the model employed was developed previously for the Trinity River Authority[14]. The reader is referred to that report for a detailed discussion of the model framework. The following sections discuss the model of the river downstream of the dam. These discussions include model segmentation, geometry,

kinetics, and evaluation of the calculated dissolved oxygen profiles. Some of the technical considerations regarding the modeling methodology have been presented in the previous sections and these discussions will not be repeated in this section.

1. Segmentation and Geometry. The model includes the portion of the Trinity River below the proposed Tennessee Colony Dam from river mile 323.5 to river mile 228. The information from previous modeling work[14] led to a division of this part of the river into five segments. A summary of the exponents and coefficients for this model is shown in Table 13. Further geometry for the two flow regimes is given in Table 14.

2. Kinetics. The reaeration rates (K_a), carbonaceous removal and deoxygenation rates (K_r and K_d), nitrogenous decay rates (K_n), and benthal uptake rates (S) of the Trinity River below the Tennessee Colony Dam are discussed in the following sections.

a. Reaeration Rates. The reaeration rates were calculated according to the O'Connor-Dobbins formula discussed previously (Equation 4). The calculated rates for each segment are given in Table 15. These values should be reviewed when additional information on geometry becomes available.

b. Carbonaceous Oxygen Demand and Nitrogenous Oxygen Demand. The combined oxygen demand from carbonaceous and nitrogenous materials was expressed as ultimate oxygen demand (UOD) in this model application. UOD values of 5 mg/l and 15 mg/l were chosen to cover a reasonable range of values possible in the release water from Tennessee Colony Lake. A decay rate of 0.2/day (base e, 20°C) was chosen as being appropriate for this portion of the river.

TABLE 13

TRINITY RIVER GEOMETRY BELOW TENNESSE COLONY DAM

REACH	NO.	MILE-POINT	VELOCITY (fps)		AREA (ft^2)		DEPTH (ft)		WIDTH (ft)	
			C_U	N_U	C_A	N_A	C_H	N_H	C_W	N_W
Tennessee Colony Dam	1	323.5	0.0271	0.544	36.9	0.455	0.393	0.418	93.8	0.036
Catfish Creek	2	321	0.0338	0.507	29.5	0.492	0.480	0.385	61.6	0.106
Oakwood	3	295	0.0142	0.603	70.0	0.396	0.797	0.303	87.9	0.093
Glaze Lake	4	275	0.0142	0.603	70.0	0.396	0.797	0.303	87.9	0.093
Crockett	5	248	0.0159	0.579	62.9	0.420	0.797	0.303	78.9	0.117

TABLE 14

MODEL GEOMETRY FOR 680 CFS LOW FLOW BELOW TENNESSEE COLONY DAM

REACH	NO.	MILE-POINT	LENGTH (mi)	FLOW (cfs)	AREA (ft^2)	VELOCITY (ft/sec)	DEPTH (ft)	WIDTH (ft)	TRAVEL TIME (days)	ACCUM. TR. TIME (days)
Tennessee Colony Dam	1	323.5	2.5	680	722	0.94	6.0	120	0.16	0.16
Catfish Creek	2	321	26	710	753	0.94	6.0	125	1.69	1.85
Oakwood	3	295	20	710	954	0.74	5.8	164	1.64	3.49
Glaze Lake	4	275	27	710	954	0.74	5.8	164	2.22	5.71
Crockett	5	248	20	710	998	0.71	5.8	171	1.72	7.43

MODEL GEOMETRY FOR 3000 CFS FLOW BELOW TENNESSEE COLONY DAM

REACH	NO.	MILE-POINT	LENGTH (mi)	FLOW (cfs)	AREA (ft^2)	VELOCITY (ft/sec)	DEPTH (ft)	WIDTH (ft)	TRAVEL TIME (days)	ACCUM. TR. TIME (days)
Tennessee Colony Dam	1	323.5	2.5	3000	1421	2.11	11.18	127	0.07	0.07
Catfish Creek	2	321	26	3030	1590	1.97	10.50	147	0.81	0.88
Oakwood	3	295	20	3030	1698	1.78	9.04	188	0.68	1.56
Glaze Lake	4	275	27	3030	1698	1.78	9.04	188	0.92	2.48
Crockett	5	248	20	3030	1838	1.65	0.04	203	0.74	3.22

TABLE 15

REAERATION RATES OF TRINITY RIVER
BELOW TENNESSEE COLONY DAM

REACH	NO.	MILE POINT	K_a (1/day) base e at 20°C	
			Q = 680 cfs	Q = 3000 cfs
Tennessee Colony Dam	1	323.5	0.85	0.50
Catfish Creek	2	321	0.85	0.53
Oakwood	3	295	0.80	0.64
Glaze Lake	4	275	0.80	0.64
Crockett	5	248	0.75	0.61

c. Benthic Demand. Deoxygenation due to benthic demands was incorporated into the model. A low value of 0.5 gm/m^2-day was chosen for all segments. Due to the trapping effects of Tennessee Colony Lake, relatively small organic deposits should accumulate in the river bottom.

d. Temperature Correction Factors. The decay rates, reaeration rates, and benthal uptake rates were corrected for temperature according to the formulas provided in the previous section. A water temperature of 30°C was assumed for the simulations.

3. Dissolved Oxygen Analysis. Dissolved oxygen profiles in the river downstream of the dam were calculated for two flow regimes and for several combinations of DO and UOD concentrations in the release water. The initial dissolved oxygen levels were chosen as zero mg/l, 2 mg/l and 4 mg/l; the initial UOD concentrations were chosen as 5 mg/l and 15 mg/l. These values were chosen to indicate the expected response of the river to the range of initial conditions which could reasonably be expected as a result of water releases from the dam during low flow conditions. Figure 19 presents the calculated profiles resulting from a steady state release of 680 cfs; Figure 20 presents comparable profiles for a release of 3000 cfs.

Figure 19 shows that for the two low DO cases, the release DO concentration controls the curve and is the lowest value projected in the river. In the case of the 4 mg/l DO, the UOD concentration also becomes important: the lower UOD level appears to have little effect, while the higher UOD causes a DO sag to approximately 3.5 mg/l at a distance of 11 to 15 miles downstream of the damsite. Figure 20 shows that the river is still sensitive to the release water DO and UOD concentrations under moderate flows. Under the lower UOD loadings, the river begins recovering

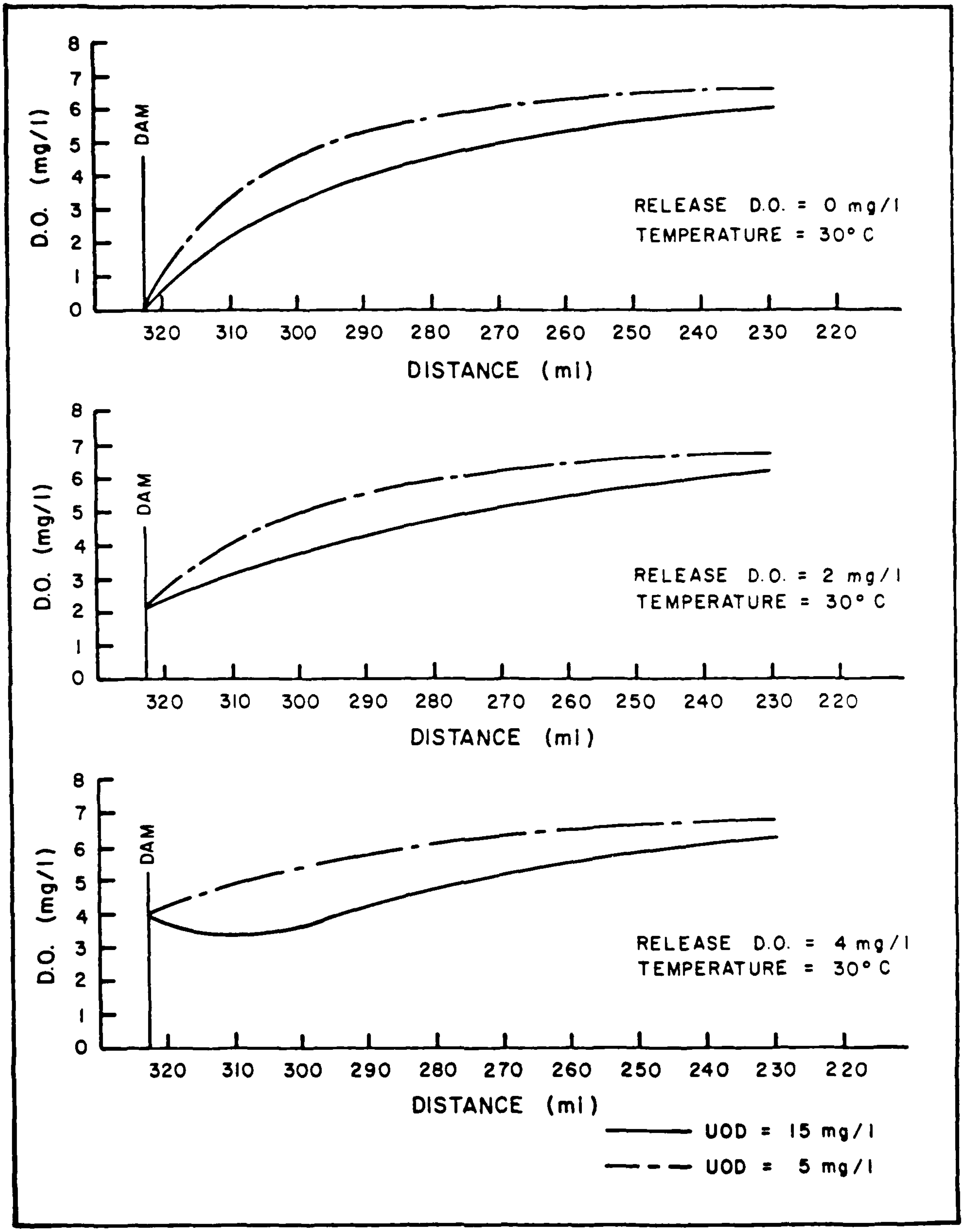


FIGURE 19
AN EVALUATION OF THE RECOVERY CHARACTERISTICS OF THE TRINITY RIVER BELOW TENNESSEE COLONY DAM (680 cfs)

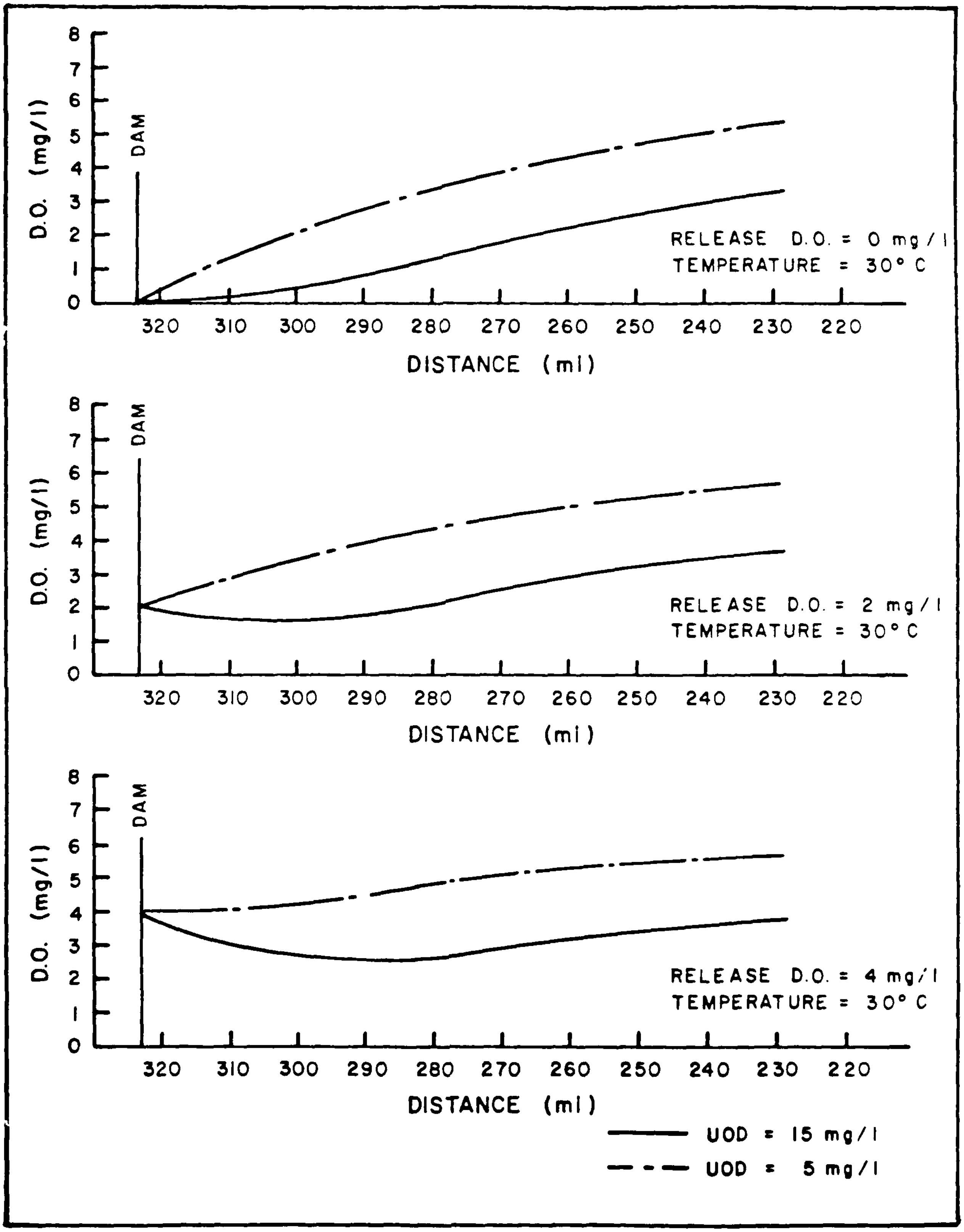


FIGURE 20
AN EVALUATION OF THE RECOVERY CHARACTERISTICS OF THE TRINITY RIVER BELOW TENNESSEE COLONY DAM (3000 cfs)

from the depressed oxygen levels introduced by the release waters. Under the higher UOD loadings, the oxygen concentration is further depressed by the exertion of the oxygen demand; the recovery portion of the profile does not begin until much farther downstream.

A further indication of the slow recovery ability of the lower Trinity is the travel time required for a stream dissolved oxygen level of 5 mg/l to be reached. This level is the most likely choice of a stream standard for this portion of the river in the future. Table 16 summarizes the approximate times and distances required to reach this DO level for the 12 combinations of release flows and 1 loadings. Under low flow conditions, the standard would be met approximately 13.5 miles downstream of the dam in the best case, and 54.5 miles downstream in the worst case. Under the higher flow, as the reaeration coefficients are lowered, the time required to recover to a DO level of 5 mg/l increases, as does the equivalent distance downstream. In the best case, a DO level of 5 mg/l will be reached approximately 51.5 miles downstream of the dam; in the worst case, over 100 miles downstream.

These results indicate the sensitivity of water quality in the Trinity River to the quality of the Tennessee Colony Lake release waters. The design and operation of the proposed release structures can directly affect the quality of the Trinity River for a significant distance downstream of the dam by their control of the dissolved oxygen concentration in the release waters.

TABLE 16

ESTIMATED DISSOLVED OXYGEN RECOVERY CHARACTERISTICS DOWNSTREAM OF PROPOSED TENNESSEE COLONY DAM

TEST RELEASE FLOW (cfs)	TEST RELEASE WATER QUALITY		RECOVERY POINT[3]	
	D.O.[1] (mg/l)	UOD[2] (mg.l)	DISTANCE DOWNSTREAM OF DAM (miles)	TIME OF TRAVEL (days)
680	0	15	54.5	4.00
680	2	15	54.5	4.00
680	4	15	54.5	4.00
680	0	5	26.5	1.72
680	2	5	21.5	1.40
680	4	5	13.5	0.87
3000	0	15	>100	>4.00
3000	2	15	>100	>4.00
3000	4	15	>100	>4.00
3000	0	5	78.5	2.59
3000	2	5	69.5	2.28
3000	4	5	51.5	1.66

[1]D.O. = Dissolved Oxygen

[2]UOD = Ultimate Oxygen Demand = sum of long-term carbonaceous and nitrogenous oxygen demands

[3]Point at which a D.O. concentration of 5 mg/l is achieved following a sag or depression below 5 mg/l (See Figures 19 and 20)

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PREDICTIVE MODELING FOR THE PROPOSED TENNESSEE COLONY LAKE BASE--ETC(U)
JUL 78 J A NUSSER, P J YOUNG   DACW63-77-C-0003
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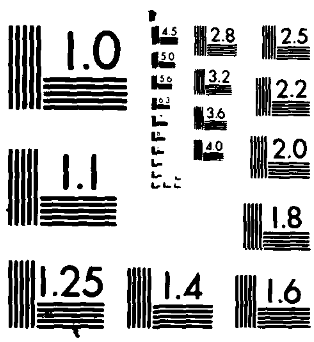

MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

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